UNIVERSITY OF IOWA STUDIES IN ENGINEERING

Bulletin 21

STUDIES OF ONE AND TWO-HANDED WORK

I. Grasping Small Parts from Different Type Bins

II. Grasping Various Sized Parts

III. Positioning Small Parts

By

Ralph M. Barnes
Professor of Industrial Engineering
and Director of Personnel
College of Engineering
University of Iowa

Marvin E. Mundel
Instructor in Industrial Engineering
College of Engineering
University of Iowa

and

John M. MacKenzie
Graduate Student in Mechanical Engineering
College of Engineering
University of Iowa

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STUDIES OF ONE AND TWO-HANDED WORK

Introduction.—An important factor in the development of our civilization has been our ability to do things without knowing how or why we do them. From the time man first used the stone ax as a tool there has been a constant improvement in mechanical devices which enables him to do more work in less time. Although there has been a steady improvement in tools and machines, the basic principles underlying their effective use by the worker have not received their share of study.

Some progress is possible without this basic knowledge, but most rapid advances will occur only when we understand more fully the different factors that influence one's ability to use his hands effectively.

For some years research work has been carried on in the Industrial Engineering Laboratory at the University of Iowa with the purpose of finding fundamental data applicable to manual work.

This bulletin is the fifth[1] in a series describing investigations of hand motions used in factory work. The first part of this bulletin gives the results of a study of grasping small parts from different type bins; part two deals with grasping various sized parts; and part three gives the results of a study of positioning small parts.

Although the data were taken with the most meticulous care, and with all the accuracy obtainable with the measuring devices that were used, the point must be noted that certain inevitable variations were introduced as a result of the fact that the movements being measured were those of human, as distinct from purely mechanical subjects.

As general conclusions could safely be based only on investigations of a much broader scope than those reported in this bulletin

[1]Other bulletins in this series are: Bulletin 6, "An Investigation of Some Hand Motions Used in Factory Work," 1936; Bulletin 12, "Studies of Hand Motions and Rhythm Appearing in Factory Work," 1938; Bulletin 16, "A Study of Hand Motions Used in Small Assembly Work," 1939; Bulletin 17, "A Study of Simultaneous Symmetrical Hand Motions," 1939.

no such general statements are presented. Conclusions at the end of each of the several studies are based merely on the results of that particular investigation.

The investigations reported in this bulletin were made in the Industrial Engineering Laboratory[2] at the University of Iowa.

Acknowledgments.—The writers wish to express their indebtedness to Dr. Mary T. Hasley, Willoughby A. Lee, W. C. Pooler, Thomas McVicker, and to John P. Sandoval, who assisted in analyzing the data and in tabulating the results of the studies presented in this bulletin.

Acknowledgment is made to the Works Projects Administration for assistance supplied in measuring the time elements as recorded by the kymograph in certain of these studies.

Special thanks are due to Norma Englert for assistance in editing the manuscript and in reading the proof. Likewise, to Robert E. Box who prepared all drawings and checked the calculations for this bulletin.

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[2]For a description of the laboratory see: "The New Emphasis in Time and Motion Study," by Ralph M. Barnes, *Journal of Engineering Education,* Vol. 16, No. 3, p. 239-248, Nov. 1935.

PART I

GRASPING SMALL PARTS FROM DIFFERENT TYPE BINS

by

Ralph M. Barnes
Marvin E. Mundel

Object.—The object of this investigation was to determine the effect of various primary conditions of involvement of the operator upon the amount of time required for grasp, transport loaded, release load, and transport empty when grasping small parts from two different types of bins.

One type of bin permitted the operator to use a hook grasp and the other type required the operator to use a pressure or pinch grasp. A *hook grasp* requires a special type of bin, so designed that the parts are fed onto a flat tray extended out from the bin. The operator grasps the parts from this tray by placing his index finger upon a part and his thumb either slightly under or against the edge of the tray, grasping the part between the balls of his index finger and thumb as the part is drawn over the edge of the tray. A *pinch grasp* is made by placing both the thumb and index finger in contact with the part and lifting the part out of the bin.[3]

The three primary conditions of involvement studied in this investigation were (1) motions performed with only the right hand, (2) motions performed with only the left hand, and (3) motions performed simultaneously with both hands in a symmetrical fashion.

Parts Used.—The parts grasped from the bins were steel machine screw nuts for machine screws Nos. 2 and 8 A.N.S. (American National Standard). The important dimensions of these parts are: No. 2 nut $\frac{3}{16}$″ across flat sides and $\frac{1}{16}$″ thick; No. 8 nut $1\frac{1}{32}$″ across flat sides and $\frac{1}{8}$″ thick. The two types of bins used are shown

[3]See, "A Study of Hand Motions Used in Small Assembly Work," Ralph M. Barnes and M. E. Mundel, *University of Iowa Studies in Engineering,* Bull. No. 16, Jan. 1939, pp. 10-19 and 28-40.

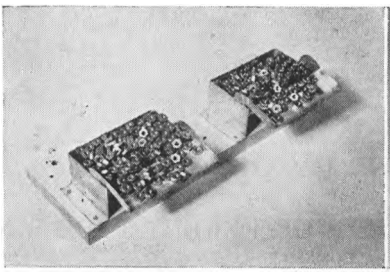


Fig. 1. Bin with tray.

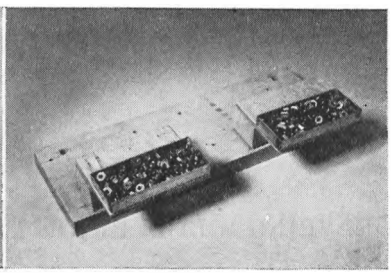


Fig. 2. Rectangular bin.

in Figs. 1 and 2. Fig. 1 shows the bin with tray which permits a hook grasp. Fig. 2 shows the rectangular bin which requires a pinch grasp.

Equipment Used in Making the Study.—In order to avoid having the timing apparatus interfere with the normal motions of the operator, the interruption of various beams of light falling on photoelectric cells and the electrical recording kymograph were used to time the four therbligs of the hand motion cycle.

The workplace was arranged as shown in Fig. 3. The electrical connections from the workplace to the electrical recording kymograph are shown in Fig. 4.[4]

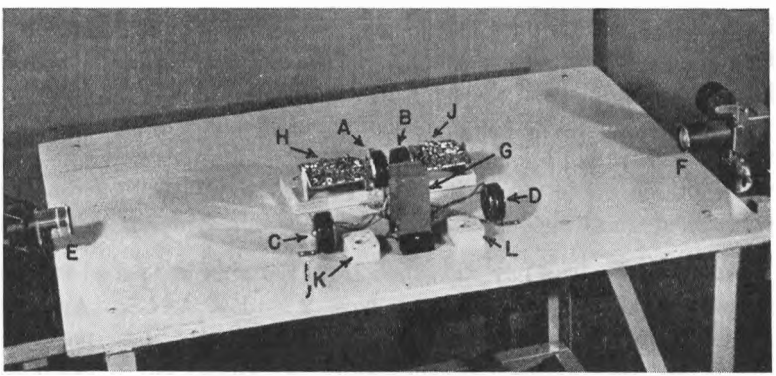


Fig. 3. Arrangement of the workplace. A, B, C, D,—photoelectric cells; E, F, G,—light sources; H, J,—bins; K, L,—holes into which parts were released.

[4]When the operator used his right hand only, the electrical connections were

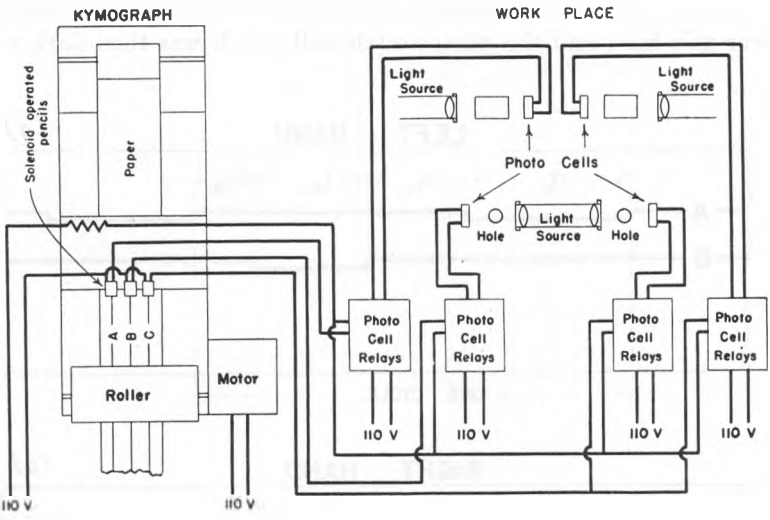
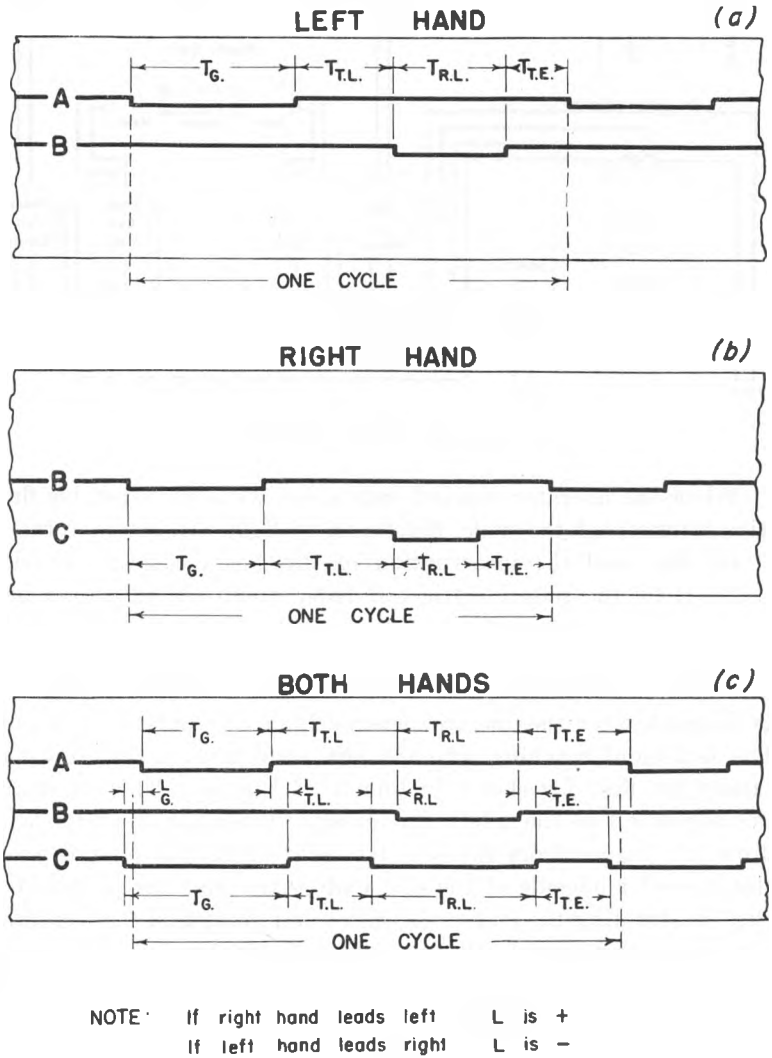


Fig. 4. Wiring diagram.

When the operator reached into a bin with his hand, his finger tips interrupted the wide, flat, beam of light passing over the top of the bin, and the interruption of this beam caused the relay, operated by the photoelectric cell from which the light had been cut off, to close the circuit of the solenoid operated pencil which it controlled. Fig. 5a is a reproduction of one cycle of the record taken on the strip of paper passing at constant velocity through the kymograph when the operator was working with only his left hand. The left hand reaching into the left hand bin on the workplace caused the first jog shown in line A of Fig. 5a. This jog marks the beginning of the select and grasp. When the operator withdrew his fingers from the bin, the light again fell on the photoelectric cell alongside of the bin, ending the first jog in line A of Fig. 5a, denoting the end of the select and grasp and the beginning of the transport loaded. Since the paper moved at constant velocity, the length of this first jog in line A is a measure of the amount of time required for select and grasp. When the operator brought the part, which he had grasped, over the hole in the table into

rearranged so that the two photoelectric cells which were interrupted by the right hand, in the course of the cycle, served to operate two separate solenoid operated pencils in the same manner as the left hand. These additional connections are not shown in Fig. 4, in order to simplify the wiring diagram.

which the part was released, he cut off the beam of light passing over this hole, and the photoelectric cell which was thus darkened



NOTE: If right hand leads left L is +
If left hand leads right L is −

Fig. 5. Reproduction of one cycle of the record made by solenoid operated pencils on the kymograph when the operator was working (a) with his left hand only, (b) with his right hand only, and (c) with both hands.

actuated its relay, causing the solenoid operated pencil making line B in Fig. 5a to make the first jog in this line. This marked the end of the transport loaded and the beginning of the release load. When the operator finished releasing the part and started moving his hand back to the bin, the light again fell on the cell alongside of the release hole, ending the first jog in line B. This marked the end of the release load and the beginning of the transport empty. When the operator again reached into the bin he caused the second jog in line A, marking the end of the transport empty and the beginning of the next cycle. When the right hand was used, the jogs occurred in lines B and C as shown in Fig. 5b. Lines B and C of Fig. 5b correspond to lines A and B of Fig. 5a respectively, and were interpreted in the same manner but refer to the time required for the various therbligs when the right hand alone was used.

The method of analysis of the data for both hands working simultaneously is shown in Fig. 5c. Lines A and B of Fig. 5c were connected to the cells upon which fell the beams of light which were interrupted by the left hand as has been previously explained, while the solenoid operated pencil which made line C was connected to both of the cells whose controlling light beams were in the path of the right hand. Since the hands were working simultaneously and in a symmetrical fashion, the jogs in line C which were made when the right hand was over the release hole may be differentiated from those which were made when the hand grasped a part from the bin by their correspondence to the jogs in lines A or B. Since the paper moved through the kymograph at a uniform velocity of 31.9 inches per second, the time for each therblig, with all three conditions of involvement, was determined in thousandths of a second. An additional feature of the data taken in connection with the two-handed work is that the *lead* or priority of one hand over the other in beginning each therblig was determined in thousandths of a second, as well as the time required for each therblig. The method of measuring these leads is indicated in Fig. 5c. Each lead is marked with the letter L and with a subscript denoting the therbligs to which it applies.

The sequence of motions of either hand when either working alone or simultaneously with the other hand was as follows:

Steps Used in Performing One Cycle	Name of Therblig	Time for Therblig in Fig. 5[5]
1. Select and grasp a nut from bin	Select and grasp	$T_{G.}$
2. Move nut to "release hole" in table top	Transport loaded	$T_{T.L.}$
3. Drop nut into hole in table top	Release load	$T_{R.L.}$
4. Move hand back to bin for next part	Transport empty	$T_{T.E.}$

Procedure.—The operators first practiced grasping twenty-five nuts, all of the same size, and one at a time, from the bin with tray (hook grasp), using the right hand. They then practiced grasping twenty-five nuts, all of the same size, and one at a time, from the rectangular bin (pinch grasp), using the right hand. Similarly, they then practiced grasping twenty-five nuts from the bin with tray with the left hand, then twenty-five nuts from the rectangular bin with left hand, then fifty nuts from the two bins with trays using both hands simultaneously and symmetrically, and then fifty nuts from the rectangular bins using both hands. The two handed practice, although involving twice as many nuts as the one handed practice, involved the same number of motion cycles with each hand, viz., twenty-five.

After this practice the operator grasped thirty-five nuts with the right hand from the bin with tray (hook grasp) and the data were recorded for the last twenty cycles. In a like manner twenty cycles were recorded using the right hand and rectangular bin (pinch grasp), left hand and bin with tray, left hand and rectangular bin, both hands and bins with trays, both hands and rectangular bins, again with both hands and rectangular bin, both hands and bins with trays, left hand and rectangular bin, left hand and bin with tray, right hand and rectangular bin, and finally, right hand and bin with tray, all in the order of enumeration given. (When both hands were used, twenty pairs of cycles were recorded.)

Five male operators were tested with the No. 2 (small) nuts and five male operators with the No. 8 (large) nuts, in both cases, using the procedure just outlined. Four of the operators who worked with the No. 2 nuts also worked with the No. 8 nuts.

[5]In Fig. 5c, each therblig carries an additional subscript, R or L, denoting the hand to which it applies.

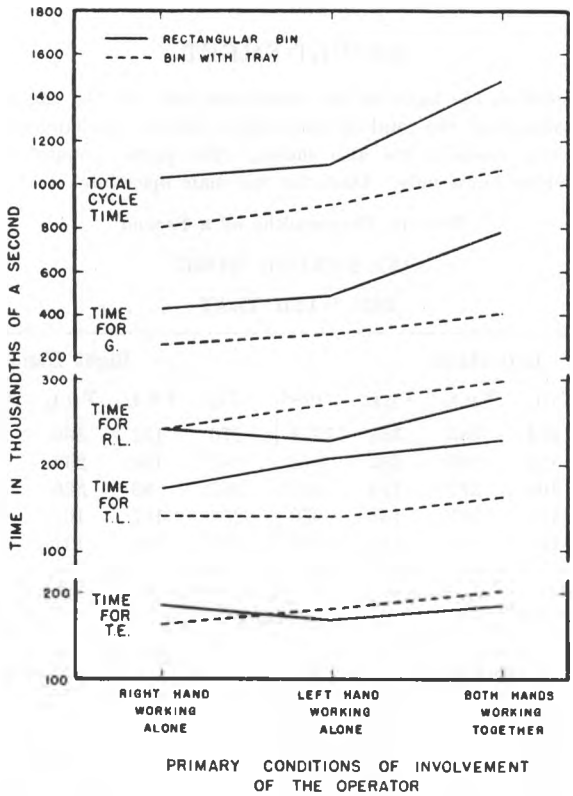


Fig. 6. Curves showing the averages of median values selected on the basis of the total cycle time. Results from five male operators working with No. 2 nuts and five working with No. 8 nuts have been combined.

The operators were all college students and, during the runs for which data were taken, were instructed to work as rapidly as possible.

Results.—The data were all taken from the paper passing under the solenoid operated pencils of the electrical recording kymograph. Fifteen consecutive cycles were analyzed for each run with each type of grasp and with each condition of involvement (with both the large and small nuts). Measurements were made to the nearest thousandths of a second and the data tabulated. The median value of the time required by each operator (with both the large and small nuts) under each of the experimental conditions was selected

TABLE I

RESULT SHEET

Medians selected on the basis of the total cycle time for the one-handed work and on the average of the total of both hands for the two-handed work. The averages of the medians are also shown. The parts grasped were No. 2 (A.N.S.) machine screw nuts. Data for five male operators.

Time in Thousandths of a Second

ONE-HANDED WORK

BIN WITH TRAY

	Left Hand					Right Hand				
Op.	$T_{G.}$	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total	$T_{G.}$	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total
1	280	204	383	351	1218	276	132	390	217	1015
2	377	132	360	102	971	341	130	259	97	827
3	261	164	372	194	991	353	93	326	169	941
4	243	175	301	151	870	258	187	107	239	791
5	284	177	192	110	763	242	162	157	156	717
Av.	289	170	322	182	963	294	141	248	176	858

RECTANGULAR BIN

	Left Hand					Right Hand				
Op.	$T_{G.}$	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total	TG.	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total
1	651	332	229	244	1456	638	223	416	273	1550
2	458	183	327	167	1135	407	144	305	160	1016
3	543	202	335	149	1229	425	174	300	171	1070
4	360	303	192	150	1005	474	202	195	122	993
5	620	199	149	163	1131	459	211	211	180	1061
Av.	526	244	246	175	1191	481	191	285	181	1138

by the total cycle time. Since there were thirty analyzed cycles for each of the different experimental conditions, this necessitated averaging two cycles to obtain the median. The time for the individual therbligs of these two selected cycles were averaged to give the subdivisions of the median. The median value was used in preference to the average because the operators were only partly skilled and the median would be less affected than the average by isolated extremely high or low values. Tables I and II give a summary of these data for the No. 2 (small) and No. 8 (large) nuts respectively. These data have been combined and are presented graphically in Fig. 6.

Table I continued

TWO-HANDED WORK

BIN WITH TRAY

Op.	$T_{G.}$ (R)*	$T_{G.}$ (L)**	$T_{T.L.}$ (R)	$T_{T.L.}$ (L)	$T_{R.L.}$ (R)	$T_{R.L.}$ (L)	$T_{T.E.}$ (R)	$T_{T.E.}$ (L)	Av. Total $\frac{R+L}{2}$
1	454	388	161	171	350	402	198	206	1165
2	499	431	123	130	375	379	131	164	1116
3	415	413	158	155	381	391	379	260	1276
4	398	369	273	159	201	347	221	192	1080
5	393	450	157	123	207	186	158	177	926
Av.	432	410	174	148	303	341	217	200	1113

RECTANGULAR BIN

Op.	$T_{G.}$ (R)	$T_{G.}$ (L)	$T_{T.L.}$ (R)	$T_{T.L.}$ (L)	$T_{R.L.}$ (R)	$T_{R.L.}$ (L)	$T_{T.E.}$ (R)	$T_{T.E.}$ (L)	Av. Total $\frac{R+L}{2}$
1	909	821	188	212	435	434	169	222	1695
2	890	854	167	294	356	303	146	111	1561
3	693	653	208	260	317	324	225	210	1445
4	673	549	224	226	338	385	110	141	1323
5	794	718	229	279	146	123	190	268	1374
Av.	792	719	203	254	318	314	168	190	1479

* (R) Therbligs of right hand.
** (L) Therbligs of left hand.

Conclusions.—(Since the results with both sizes of nuts were essentially the same, the results have been combined to give the following conclusions.)

1. IN REGARD TO TOTAL CYCLE TIME

Effect of primary conditions of involvement

The least time was required for a total cycle when only the right hand was used. A cycle with the left hand required, on the average, 8% more time, and a cycle with both hands, 37% more time. However, since two cycles were performed simultaneously when the two hands were used, the time chargeable to each cycle was 31% less than when only the right hand was used.

Effect of type of grasp as necessitated by bin

The least time was required for a total cycle when the hook grasp (bin with tray) was used. A total cycle containing a pinch grasp (rectangular bin) required, on the average, 30% more time.

TABLE II

RESULT SHEET

Medians selected on the basis of the total cycle time for the one-handed work and on the average of the total of both hands for the two-handed work. The averages of the medians are also shown. The parts grasped were No. 8 (A.N.S.) machine screw nuts. Data for five male operators.

Time in Thousandths of a Second

ONE-HANDED WORK

BIN WITH TRAY

	Left Hand					Right Hand				
Op.	$T_{G.}$	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total	T_{G}	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total
1	358	114	267	155	894	249	92	277	133	751
2	401	117	245	154	917	275	162	305	217	959
3	414	101	159	136	810	304	117	225	132	778
4	187	108	223	143	661	132	131	213	145	621
5	315	117	215	316	963	197	203	159	146	705
Av.	335	111	222	181	849	231	141	236	155	763

RECTANGULAR BIN

	Left Hand					Right Hand				
Op.	$T_{G.}$	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total	$T_{G.}$	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total
1	494	139	246	161	1040	378	116	235	203	932
2	554	146	295	115	1110	578	187	113	215	1093
3	478	224	135	206	1043	388	157	166	223	934
4	351	145	192	158	846	228	152	241	176	797
5	423	208	183	177	991	362	177	239	151	929
Av.	460	172	210	163	1006	387	158	199	194	937

2. IN REGARD TO GRASP TIME

Effect of primary conditions of involvement

The least time was required for grasp when only the right hand was used. A grasp with the left hand required, on the average, 16% more time, and a grasp with both hands (from two different bins) 71% more time. However, since two grasps were performed simultaneously when the two hands were used, the time chargeable to each grasp was 15% less than when only the right hand was used.

Effect of type of grasp as necessitated by bin

The least time was required for grasp when the hook grasp (bin with tray) was used. A pinch grasp (rectangular bin) required, on the average, 74% more time.

Table II continued

TWO-HANDED WORK

BIN WITH TRAY

Op.	$T_{G.}$ (R)	$T_{G.}$ (L)	$T_{T.L.}$ (R)	$T_{T.L.}$ (L)	$T_{R.L.}$ (R)	$T_{R.L.}$ (L)	$T_{T.E.}$ (R)	$T_{T.E.}$ (L)	Av. Total $\frac{R+L}{2}$
1	470	379	133	285	254	175	206	225	1063
2	428	456	240	134	254	338	233	203	1143
3	338	387	151	102	280	233	227	209	963
4	245	277	138	141	231	208	194	175	804
5	390	500	175	116	392	406	143	139	1130
Av.	374	400	167	156	282	272	200	190	1021

RECTANGULAR BIN

Op.	$T_{G.}$ (R)	$T_{G.}$ (L)	$T_{T.L.}$ (R)	$T_{T.L.}$ (L)	$T_{R.L.}$ (R)	$T_{R.L.}$ (L)	$T_{T.E.}$ (R)	$T_{T.E.}$ (L)	Av. Total $\frac{R+L}{2}$
1	699	723	234	211	116	162	259	185	1294
2	989	1059	421	132	156	298	171	180	1703
3	825	992	291	203	256	199	168	196	1565
4	624	806	301	187	268	182	193	181	1371
5	667	734	183	105	392	355	180	198	1407
Av.	761	863	286	168	238	239	194	188	1468

3. IN REGARD TO TRANSPORT LOADED TIME

Effect of primary conditions of involvement

The least time was required for transport loaded when only the right hand was used. A transport loaded with the left hand required, on the average, 10% more time, and a transport loaded with both hands, 23% more time. However, since two transport loadeds were performed simultaneously when the two hands were used, the time chargeable to each transport loaded was 38% less than when only the right hand was used.

Effect of type of grasp as necessitated by bin

The least time was required for transport loaded when the hook grasp (bin with tray) preceded the transport. A transport loaded following a pinch grasp (rectangular bin) required, on the average, 38% more time.

4. IN REGARD TO RELEASE LOAD TIME

Effect of primary conditions of involvement

The least time was required for release load when either the right or left hand alone was used, there being no appreciable difference

between the hands used singly. A release load with both hands required, on the average, 19% more time. However, since two release loads were performed simultaneously when the two hands were used, the time chargeable to each release load was 40% less than when only one hand was used.

Effect of type of grasp as necessitated by bin

The least time was required for transport empty when a pinch grasp (rectangular bin) followed. A transport empty when followed by a hook grasp (bin with tray) required, on the average, 9% more time. This 9% is a fairly reliable difference and was probably caused by the therblig select taking place, to some extent, during the transport empty when preceding a hook grasp (bin with tray).

5. IN REGARD TO TRANSPORT EMPTY TIME

Effect of primary conditions of involvement

The least time was required for transport empty when either the right or left hand alone was used, there being no appreciable difference between the hands used singly. A transport empty with both hands required, on the average, 10% more time. However, since two transport emptys were performed simultaneously when the two hands were used, the time chargeable to each was 45% less than when only one hand was used.

Effect of type of grasp as necessitated by bin

The least time was required for transport empty when a pinch grasp followed. A transport empty when followed by a hook grasp required, on the average, 1.5% more time. This 1.5% is a fairly reliable difference and was probably caused by the therblig select taking place, to some extent, during the transport empty when preceding a hook grasp.

6. The data indicated that operators who were relatively efficient, as compared to other operators, at performing the motions of the task when using only the right hand, were also relatively efficient in performing the task simultaneously with both hands. The correlation ratio[6] between the total cycle time when working with the right hand alone and simultaneously with both hands was +.76 over all types of grasp, sizes of nuts, and all operators.

7. The data indicate that operators who were relatively efficient,

[6]This correlation ratio is a measure of the linear relationship between two

as compared to other operators, at grasping the parts when using only the right hand, were also relatively efficient in performing the grasp simultaneously with both hands. The correlation ratio between the grasp time when working with only the right hand and the average grasp time per hand[7] when working simultaneously with both hands was +.81 over all types of grasp, sizes of nuts, and all operators.

8. The conclusions 6 and 7 suggest that under the conditions observed in this investigation and with the operators studied, there was considerable evidence to indicate that a good "one-handed" operator was also a good "two-handed" operator, and a relatively poor "one-handed" operator was also a relatively poor "two-handed" operator. This suggests that the introduction of two-handed simultaneous work in place of less efficient "one-handed" work will not inconvenience any one operator very much more than another operator.

9. When the operators worked with both hands, with either type of grasp and with either size of nut, they tended to lead with the right hand, that is, the right hand, in most cases, started each therblig slightly before the left hand. Of the 600 cycles of two-handed work which were analyzed, the right hand started the grasp before the left hand 73% of the time, the right hand started the transport loaded before the left hand 64% of the time, the right hand started the release load before the left hand 60% of the time, and the right hand started the transport empty before the left hand 69% of the time.

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variables. A perfect relationship is indicated by a +1.0 correlation ratio. A positive sign in front of the ratio is used to indicate a direct relationship and a negative sign to indicate an inverse relationship. For a detailed explanation of the correlation ratio see: Croxton, F.E., and Cowden, D.J., "Practical Business Statistics," Prentice-Hall, New York, 1937, pp. 405-427, or any statistics textbook.

[7]Average grasp time per hand equals time for grasp with right hand plus time for grasp with left hand divided by two. Times used in correlation are median values taken when hands worked together, selected on the basis of the average grasp time per hand.

PART II

GRASPING VARIOUS SIZED PARTS

by

RALPH M. BARNES
MARVIN E. MUNDEL

Object.—The two-fold object of this investigation was (1) to determine the effect of various primary conditions of involvement of the operator upon the amount of time required for grasp, transport loaded, release load, and transport empty; and (2) to determine the effect of certain added conditions surrounding grasp, such as protrusions on the parts, pre-positioning and non-pre-positioning bins, and other special conditions, with a series of wooden cubes (blocks) the smallest of which could be easily grasped with the thumb and one or two fingers, and the largest of which required the use of the whole hand, fully extended.

In this report, the term "primary condition of involvement" refers to the number of limbs of the operator used in performing the task, that is, (a) motions performed with only the right hand, (b) motions performed with only the left hand, and (c) motions performed simultaneously with both hands in a symmetrical fashion.

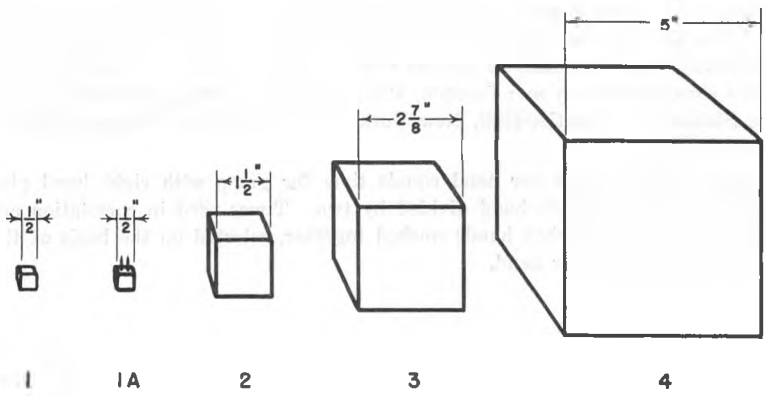

Fig. 7. Blocks used in study.

The other variables introduced in this investigation are described below.

Parts Used.—The five blocks used with the conditions of secondary involvement (amount of hand used and extent of use) they imposed upon the operator were as follows:

Block No.	Dimensions of Block	Shape of Block	Secondary Involvement of Operator	Avg. Wgt. of 1 Block in Ounces
1	½"x½"x½"	Cube	Thumb and two fingers closely opposed	0.048
1A	½"x½"x½"	Cube with protrusions	Same as with No. 1 but care required to avoid pricking fingers	0.056
2	1½"x1½"x1½"	Cube	Thumb and three fingers moderately opposed	1.000
3	2⅞"x2⅞"x2⅞"	Cube	Thumb and four fingers Palm almost in use	6.700
4	5"x5"x5"	Cube	Whole hand including palm Hand fully extended	36.800

The dimensions of the blocks and their shape are shown in Fig. 7.

The two bins which were used with block No. 1 are shown in Figs. 8 and 9. Only the rectangular bin was used with block No. 1A. (See Fig. 8).

The two bins which were used with block No. 2 were similar to the bins used with block No. 1 and are shown in Figs. 10 and 11.

Only one bin was used with block No. 3, a pre-positioning slide similar to the pre-positioning slides shown in Figs. 9 and 11. However, during part of the test, a fixed "corner" was placed at the lower end of the slide as is shown in Fig. 12. This was done in

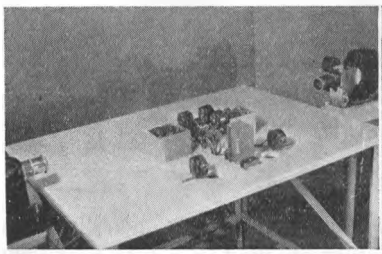

Fig. 8. Arrangement of workplace. One-half inch blocks in rectangular bins.

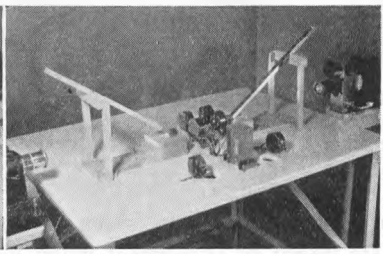

Fig. 9. Arrangement of workplace. One-half inch blocks pre-positioned in slides.

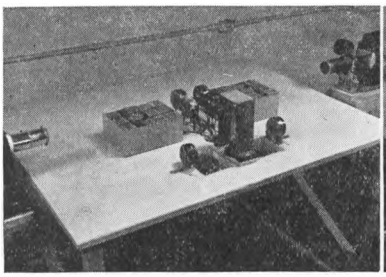

Fig. 10. Arrangement of work-place. One and one-half inch blocks in rectangular bins.

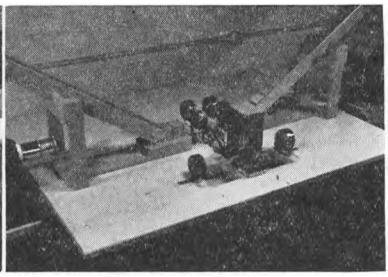

Fig. 11. Arrangement of work-place. One and one-half inch blocks pre-positioned in slides.

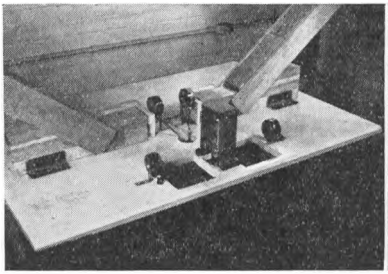

Fig. 12. Arrangement of work-place. Two and seven-eighths inch blocks with fixed 'corner'' in place.

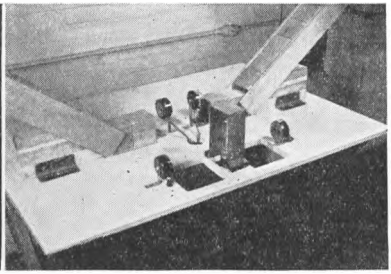

Fig. 13. Arrangement of work-place. Two and seven-eighths inch blocks pre-positioned in slide.

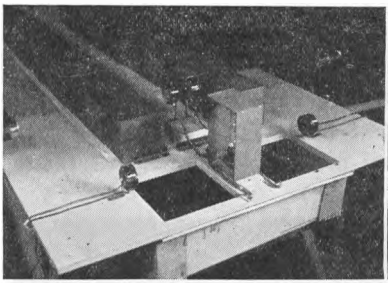

Fig. 14. Arrangement of work-place. Five inch blocks one against the other in row.

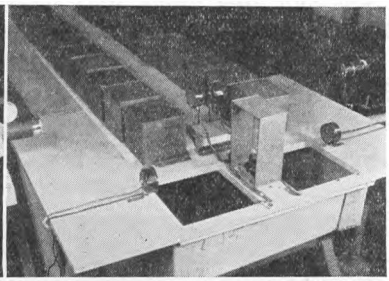

Fig. 15. Arrangement of work-place. Five inch blocks pre-positioned on belt—¾ inch spacers between blocks.

order to simulate the sides of the other blocks against which the parts might be in contact when loosely stacked in a tote box. The ''corner'' came within one-eighth inch of the sides of the blocks.

The different type of pre-positioned delivery shown in Figs. 14

and 15 was used with block No. 4 because the weight of these blocks would have made a pre-positioning slide dangerous as the operator might have been injured with a bin of that type if his fingers had become caught in the descent of the blocks. The two conditions surrounding the grasps of block No. 4 were (a) the blocks were brought forward on the feeder apron with spacers in between successive blocks allowing the fingers to descend immediately in between two blocks as is shown in Fig. 15, and (b) the blocks were fed forward without spacers, one block against the next, necessitating grasping blocks as is shown in Fig. 14.

Equipment Used in Making the Study.—The workplace used with blocks Nos. 1 and 1A is shown in Figs. 8 and 9; the workplace used with block No. 2 is shown in Figs. 10 and 11; the workplace used with the No. 3 blocks is shown in Figs. 12 and 13; and the workplace used with block No. 4 is shown in Figs. 14 and 15.

Since in all cases a similar method was used to time the various therbligs of which the task consisted, a detailed description of the equipment used with only one size of block will be given.

The electrical connections from the workplace to the electrical recording kymograph are shown in Fig. 16. These connections were the same for all blocks.

When the operator reached into the pre-positioning slide or into the rectangular bin, as with block No. 1, his fingers interrupted a beam of light as soon as they were within one-quarter inch of the pre-positioned block which they were about to grasp or within one-

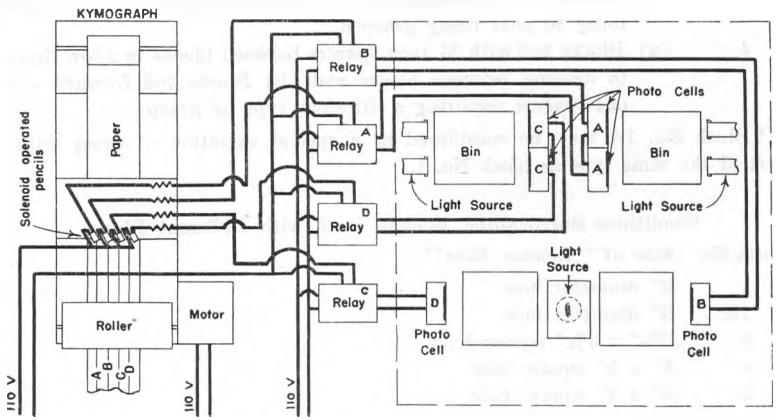

Fig. 16. Wiring diagram.

quarter inch of the top of the flush-filled bin. The interruption of this beam of light caused the relay actuated by the photoelectric cell from which the light had been cut off to close the circuit of the solenoid operated pencil which it controlled. Time measurements for the various therbligs were made by means of the electrical recording kymograph in a manner similar to that described in Part I.

The sequence of motions of either hand, when either worked alone or simultaneously with the other hand, was as follows:

Steps Used in Performing One Cycle	Name of Therblig	Time for Therblig
1—Grasp[8] one block	Grasp	$T_{G.}$
2—Move block to "release hole" in table top	Transport loaded	$T_{T.L.}$
3—Drop block in hole in table top	Release load	$T_{R.L.}$
4—Move hand back for next block	Transport empty	$T_{T.E.}$

Special Conditions Surrounding Grasp with the Different Blocks

Block No.	Different Conditions of Grasp
1	(a) Pre-positioning slide and (b) Rectangular bin
1A*	(a) Rectangular bin only
2	(a) Pre-positioning slide and (b) Rectangular bin
3	(a) Pre-positioning slide and (b) Fixed corner attached to bottom of slide to duplicate case where other parts are in close proximity to part being grasped
4	(a) Blocks fed with ¾ inch spacers between blocks to allow fingers to descend between blocks and (b) Blocks fed forward without spacers requiring a different type of grasp

* Block No. 1A may be considered as a special variation of grasp with a part of the same type as block No. 1.

Conditions Surrounding Release Load with Different Blocks

Block No.	Size of "Release Hole"
1	2″ diameter hole
1A	2″ diameter hole
2	3¾″ x 3¾″ square hole
3	5″ x 5″ square hole
4	8″ x 8″ square hole

[8]Select and Grasp with rectangular bins.

Length of the Transports with the Different Blocks

Block No.	Length of Transports (From center of block to center of "Release hole")
1	8 inches
1A	8
2	8
3	10
5	10

Procedures.—

BLOCK NOS. 1 and 1A

The operators first practiced grasping 25 blocks under each of the conditions listed below in the order given:

Arrangement No.	Block No.	Bin	Hand Used
1	1	P.P. Slide	Right
2	1	P.P. Slide	Left
3	1	P.P. Slide	Both
4	1	Rectangular	Right
5	1	Rectangular	Left
6	1	Rectangular	Both
7	1A	Rectangular	Right
8	1A	Rectangular	Left
9	1A	Rectangular	Both

The operators then grasped 35 blocks under the conditions of Arrangement No. 1 as above and the data for the last 20 cycles were recorded. In a similar fashion data were obtained with Arrangements Nos. 2, 3, 4, 5, 6, 7, 8, 9, again with 9, 8, 7, 6, 5, 4, 3, 2, and 1, all in that order. Five male college students were used as operators. They were all right handed.

BLOCK NO. 2

The operators first practiced grasping 25 blocks under each of the conditions listed below in the order given:

Arrangement No.	Block No.	Bin	Hand Used
1	2	P.P. Slide	Right
2	2	P.P. Slide	Left
3	2	P.P. Slide	Both
4	2	Rectangular	Right
5	2	Rectangular	Left
6	2	Rectangular	Both

The operators then grasped 35 blocks under the conditions of Arrangement No. 1 as above and the data for the last 20 cycles were recorded. In a similar fashion 20 cycles were recorded under the conditions of Arrangements Nos. 2, 3, 4, 5, 6, again with 6, 5, 4, 3, 2, and 1, all in that order. Five male, right-handed college students were used as operators.

BLOCK NO. 3

The operators first practiced grasping 25 blocks under each of the conditions listed below in the order given:

Arrangement No.	Block No.	Bin	Hand Used
1	3	P.P. Slide	Right
2	3	P.P. Slide	Left
3	3	P.P. Slide	Both
4	3	P.P. Slide with fixed bottom corner	Right
5	3	P.P. Slide with fixed bottom corner	Left
6	3	P.P. Slide with fixed bottom corner	Both

The operators then grasped 25 blocks under the conditions of Arrangement No. 1 as above and the data for the last 20 cycles were recorded. In a similar fashion, data were recorded under Arrangements Nos. 2, 3, 4, 5, 6, again with 6, 5, 4, 3, 2, and 1, all in that order. Five male, right-handed college students were used as operators.

BLOCK NO. 4

The operators first practiced grasping 12 blocks under each of the conditions listed below in the order given:

Arrangement No.	Block No.	Bin	Hand Used
1	4	P.P. Apron with spacers[9]	Right
2	4	P.P. Apron with spacers	Left
3	4	P.P. Apron with spacers	Both
4	4	P.P. Apron without spacers	Right
5	4	P.P. Apron without spacers	Left
6	4	P.P. Apron without spacers	Both

[9]The blocks were fed up toward the operator so that each grasp was always made from the same place. However, during that part of the experiment characterized by "P.P. Apron with spacers", the blocks were fed forward with spacers in between adjacent blocks so that the operator could slip his fingers between adjacent blocks to complete the grasp. During that part of

The operators then grasped 12 blocks under the conditions of Arrangement No. 1 as given above and data for the last 10 grasps were recorded. In a like manner data were recorded under Arrangements Nos. 2, 3, 4, 5, 6, again with 6, 5, 4, 3, 2, and 1, all in that order. Five male, right-handed college students were used as operators.

Results.—Data were all taken from the paper passing under the solenoid operated pencils of the kymograph. Fifteen consecutive cycles were analyzed for each run with each type of grasp and with each condition of involvement for blocks Nos. 1, 1A, 2, and 3. Ten consecutive cycles only were analyzed with block No. 4. Measurements were made to the nearest thousandth of a second.

The median value of the time required by each operator with each block was selected by the total cycle time. Since there were always an even number of analyzed cycles for each of the different experimental conditions, this necessitated averaging two cycles to obtain the median. Time for the individual therbligs of these two selected cycles were averaged to give the sub-divisions of the median. The median value was used in preference to the average because the operators were only partly skilled and the median would be less affected than the average by isolated extremely high and low values.

Table III gives a summary of the results obtained with blocks Nos. 1 and 1A, Table IV gives this information for block No. 2, Table V for block No. 3, and Table VI for block No. 4.

These data are presented graphically as follows: Fig. 17 for blocks Nos. 1 and 1A; Fig. 18 for block No. 2; Fig. 19 for block No. 3; and Fig. 20 for block No. 4.

Conclusions.—Blocks Nos. 1 and 1A—Half-inch Cubes

1—IN REGARD TO TOTAL CYCLE TIME

Effect of primary conditions of involvement

The least time was required for a total cycle when only the right hand was used. A total cycle with the left hand required, on the average, 7% more time, and a cycle with both hands, 38% more

the experiment denoted as "P.P. Apron without spacers", the blocks were fed forward with no spacers in between successive blocks so that the operator had to grasp them in his hand with the thumb at one side and the fingers at the other rather than grasping with the thumb over the front edge of the block and the fingers over the back edge as with spacers.

TABLE III

RESULT SHEET

Medians selected on the basis of the total cycle time for the one-handed work and on the average of the total of both hands for the two-handed work. The averages of the medians are also shown. The parts grasped were ½ inch wooden cubes. Data are for five male operators.

Time in Thousandths of a Second

ONE-HANDED WORK

	PRE-POSITIONING SLIDE SQUARE BLOCKS									
	Left Hand					Right Hand				
Op.	$T_{G.}$	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total	$T_{G.}$	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total
1	148	132	195	171	646	113	168	269	144	694
2	148	200	198	206	752	110	207	265	40	622
3	121	138	95	178	532	127	136	220	57	540
4	136	146	112	202	596	213	127	137	198	675
5	194	104	82	247	627	175	122	159	123	579
Av.	149	144	137	201	631	148	152	210	112	622
	RECTANGULAR BOX BIN SQUARE BLOCKS									
Op.	$T_{G.}$	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total	$T_{G.}$	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total
1	367	157	187	178	889	329	182	196	126	833
2	298	201	175	232	906	238	201	246	118	803
3	363	113	172	177	825	243	148	144	145	680
4	405	121	151	156	833	229	139	210	98	676
5	327	142	111	204	784	278	167	103	194	742
Av.	352	147	159	189	847	263	168	180	136	747
	RECTANGULAR BOX BIN BLOCKS WITH WIRE PROTRUSIONS									
Op.	$T_{G.}$	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total	$T_{G.}$	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total
1	255	118	214	200	787	249	135	203	155	742
2	310	209	169	210	898	219	137	264	203	823
3	331	153	98	197	779	307	135	126	132	700
4	216	161	119	203	699	227	171	239	109	746
5	268	175	122	211	776	353	168	12	195	728
Av.	276	163	145	204	788	271	149	169	159	748

time. However, since two blocks were moved simultaneously when the two hands were used, the time chargeable to each cycle was 31% less than when only the right hand was used.

Effect of type of grasp as necessitated by bin [*with plain square blocks* (*No. 1*) *only*]

The least time was required for a total cycle when the pre-positioning bin was used. (With this bin, the block was always in the same position and location for grasping.) A total cycle con-

Table III continued

TWO-HANDED WORK

	PRE-POSITIONING SLIDE					SQUARE BLOCKS			
Op.	$T_{G.}$ (R)*	$T_{G.}$ (L)**	$T_{T.L.}$ (R)	$T_{T.L.}$ (L)	$T_{R.L.}$ (R)	$T_{R.L.}$ (L)	$T_{T.E.}$ (R)	$T_{T.E.}$ (L)	Av. Total $\frac{R+L}{2}$
1	137	221	214	144	296	217	137	192	779
2	194	239	198	135	281	182	111	206	773
3	140	165	180	133	199	193	148	159	658
4	200	215	172	147	216	129	99	185	682
5	237	219	156	175	195	112	176	206	738
Av.	182	212	184	147	237	167	134	189	726
	RECTANGULAR BOX BIN					SQUARE BLOCKS			
Op.	$T_{G.}$ (R)*	$T_{G.}$ (L)**	$T_{T.L.}$ (R)	$T_{T.L.}$ (L)	$T_{R.L.}$ (R)	$T_{R.L.}$ (L)	$T_{T.E.}$ (R)	$T_{T.E.}$ (L)	Av. Total $\frac{R+L}{2}$
1	476	497	203	143	317	239	236	259	1185
2	433	426	267	260	312	259	155	183	1147
3	439	435	174	141	199	126	175	198	943
4	467	487	184	212	262	195	138	212	1078
5	589	601	206	178	155	92	161	253	1118
Av.	481	489	207	187	249	182	173	221	1094
	RECTANGULAR BOX BIN					BLOCKS WITH WIRE PROTRUSIONS			
Op.	$T_{G.}$ (R)*	$T_{G.}$ (L)**	$T_{T.L.}$ (R)	$T_{T.L.}$ (L)	$T_{R.L.}$ (R)	$T_{R.L.}$ (L)	$T_{T.E.}$ (R)	$T_{T.E.}$ (L)	Av. Total $\frac{R+L}{2}$
1	456	488	223	184	346	234	145	215	1146
2	331	662	386	189	315	173	142	212	1205
3	446	409	187	140	176	208	209	206	990
4	452	556	229	177	269	148	149	261	1121
5	432	453	226	173	201	153	156	230	1012
Av.	423	514	250	173	261	183	160	225	1095

* (R) Therbligs of right hand.
** (L) Therbligs of left hand.

taining a grasp from the rectangular bin required, on the average, 35% more time.

Effect of part grasped
(*From rectangular bin only*)

The least time was required for a total cycle when the square block with protrusions was used. A total cycle with the plain square block required, on the average, 2% more time.

2—IN REGARD TO GRASP TIME

Effect of primary conditions of involvement

The least time was required for grasp when only the right hand was used. A grasp with the left hand required, on the average,

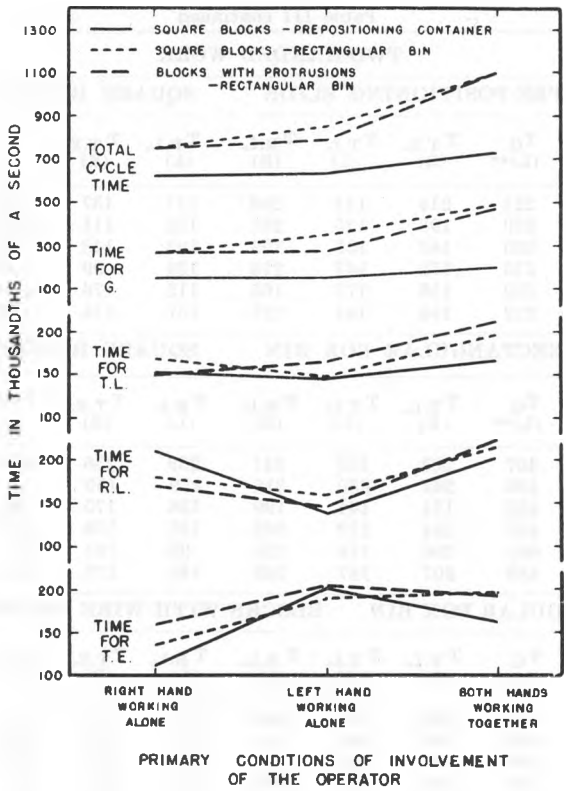

Fig. 17. Curves showing averages of the medians selected on the basis of the total cycle time for the one-handed work and on the average of the total of both hands for the two-handed work. Results are from five male operators working with 1/2 inch wooden cubes.

14% more time, and a grasp with both hands (from two separate bins) 69% more time. However, since two grasps were performed simultaneously when the two hands were used, the time chargeable to each grasp was 16% less than when only the right hand was used.

Effect of type of grasp as necessitated by bin
(*With plain square blocks only*)

The least time was required for grasp when the pre-positioning bin was used. A grasp from the rectangular bin required, on the average, 122% more time.

Effect of part grasped
(*From rectangular bin only*)

The least time was required for grasp when the square blocks

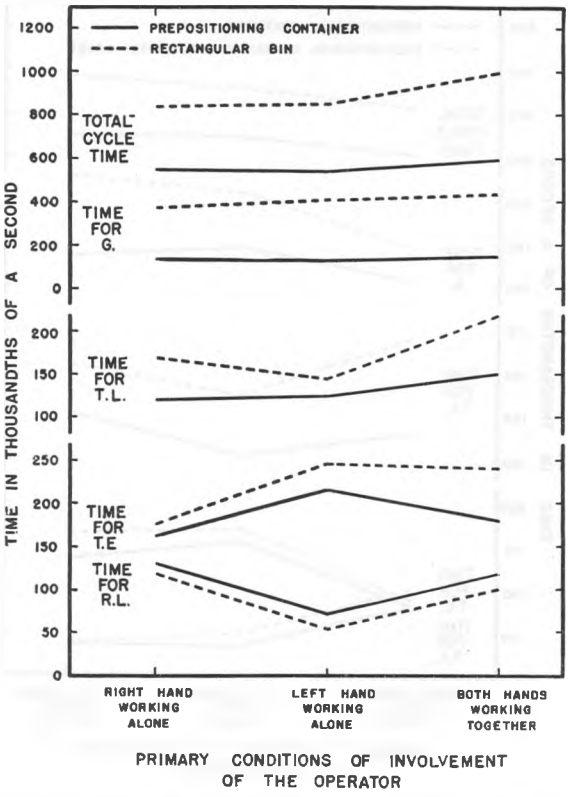

Fig. 18. Curves showing averages of the medians selected on the basis of the total cycle time for the one-handed work and on the average of the total of both hands for the two-handed work. Results are from five male operators working with 1½ inch wooden cubes.

with protrusions were grasped. A grasp of the plain square blocks required, on the average, 8% more time.

3—IN REGARD TO TRANSPORT LOADED TIME

Effect of primary conditions of involvement

The least time was required for a transport loaded when only the left hand was used. A transport loaded with the right hand required, on the average, 3% more time, and a transport loaded with both hands, 26% more time. However, since two transport loadeds were performed simultaneously when the two hands were used, the time chargeable to each transport loaded was 36% less than when only the right hand was used.

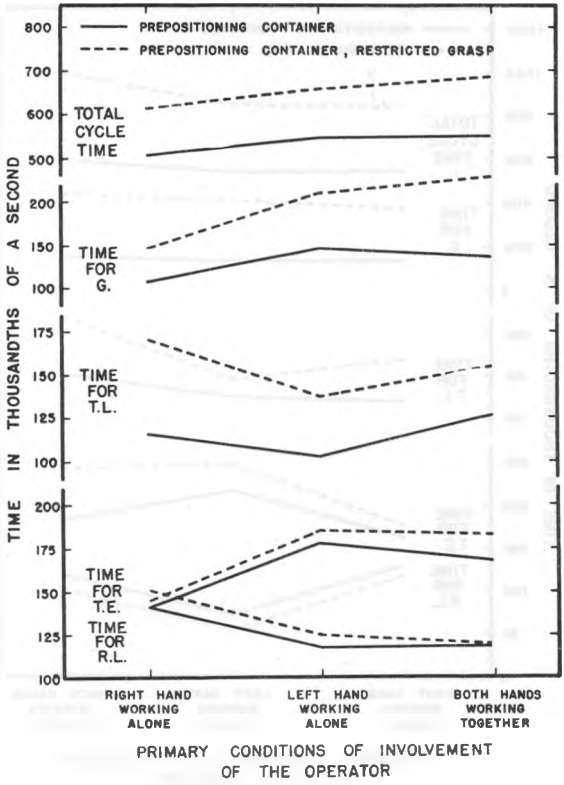

Fig. 19. Curves showing averages of the medians selected on the basis of the total cycle time for the one-handed work and on the average of the total of both hands for the two-handed work. Results are from five male operators working with 2⅞ inch wooden cubes.

Effect of type of grasp as necessitated by bin
(*With plain square blocks only*)

The least time was required for transport loaded when the prepositioning bin was used. A transport loaded from a rectangular bin required, on the average, 11% more time.

Effect of part grasped
(*From rectangular bin only*)

The least time was required for transport loaded when the plain square block was involved. A transport loaded with the square block with protrusions required, on the average, 2% more time.

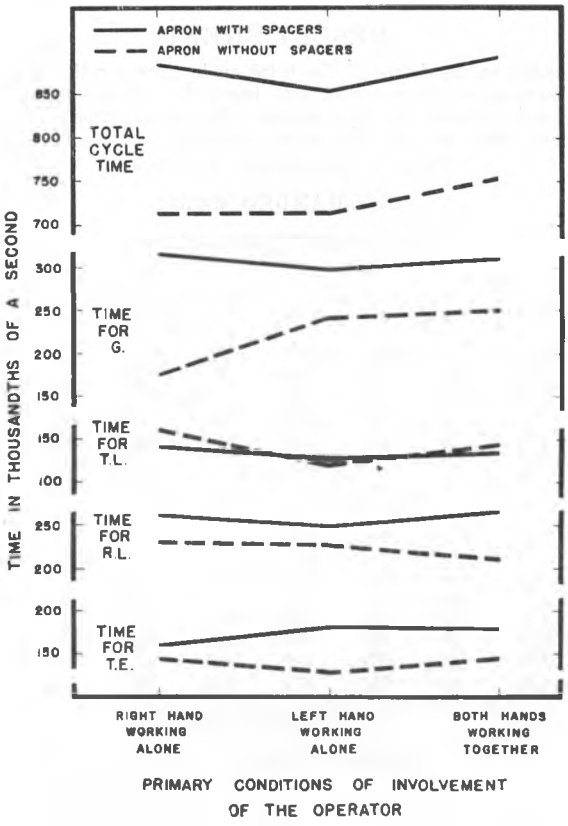

Fig. 20. Curves showing averages of the medians selected on the basis of the total cycle time for the one-handed work and on the average of the total of both hands for the two-handed work. Results are from five male operators working with 5 inch wooden cubes.

4—IN REGARD TO RELEASE LOAD TIME

Effect of primary conditions of involvement

The least time was required for release load when only the left hand was used. A release load with the right hand required, on the average, 27% more time, and a release load with both hands, 45% more time. However, since two release loads were performed simultaneously when the two hands were used, the time chargeable to each release load was 27% less than when only the left hand was used.

TABLE IV

RESULT SHEET

Medians selected on the basis of the total cycle time for the one-handed work and on the average of the total of both hands for the two-handed work. The averages of the medians are also shown. The parts grasped were 1 ½ inch wooden cubes. Data are for five male operators.

Time in Thousandths of a Second

ONE-HANDED WORK

PRE-POSITIONING SLIDE

	Left Hand					Right Hand				
Op.	$T_{G.}$	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total	$T_{G.}$	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total
1	110	186	78	247	621	137	144	135	196	612
2	120	84	80	198	482	121	95	128	131	475
3	147	136	71	254	608	137	148	120	233	638
4	106	111	103	146	466	111	95	193	91	490
5	160	100	25	231	516	170	120	73	159	522
Av.	129	123	72	215	539	135	120	130	162	547

RECTANGULAR BOX BIN

Op.	$T_{G.}$	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total	$T_{G.}$	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total
1	339	185	63	324	911	359	152	139	254	904
2	535	115	59	189	898	411	134	111	159	815
3	481	108	75	241	905	377	202	121	216	916
4	297	166	22	219	704	238	200	171	106	715
5	382	146	52	252	832	486	152	47	139	824
Av.	407	144	54	245	850	374	168	118	175	835

TWO-HANDED WORK

PRE-POSITIONING SLIDE

Op.	$T_{G.}$ (R)*	$T_{G.}$ (L)**	$T_{T.L.}$ (R)	$T_{T.L.}$ (L)	$T_{R.L.}$ (R)	$T_{R.L.}$ (L)	$T_{T.E.}$ (R)	$T_{T.E.}$ (L)	Av. Total $\frac{R+L}{2}$
1	177	175	150	172	112	105	233	209	667
2	129	151	123	99	109	91	154	176	516
3	96	181	200	161	105	56	218	232	624
4	86	100	167	179	216	98	79	177	551
5	175	193	147	120	135	150	173	145	618
Av.	133	160	157	142	136	100	172	188	595

RECTANGULAR BOX BIN

Op.	$T_{G.}$ (R)*	$T_{G.}$ (L)**	$T_{T.L.}$ (R)	$T_{T.L.}$ (L)	$T_{R.L.}$ (R)	$T_{R.L.}$ (L)	$T_{T.E.}$ (R)	$T_{T.E.}$ (L)	Av. Total $\frac{R+L}{2}$
1	442	399	213	232	166	99	242	301	1047
2	368	434	296	267	101	65	296	226	1026
3	522	548	222	203	98	16	193	300	1051
4	382	357	189	270	213	30	143	228	906
5	474	454	137	139	96	112	235	254	951
Av.	438	438	211	222	135	64	220	262	996

* (R) Therbligs of right hand.
** (L) Therbligs of left hand.

TABLE V

RESULT SHEET

Medians selected on the basis of the total cycle time for the one-handed work and on the average of the total of both hands for the two-handed work. The averages of the medians are also shown. The parts grasped were 2 7/8 inch wooden cubes. Data are for five male operators.

Time in Thousandths of a Second

ONE-HANDED WORK

PRE-POSITIONING SLIDE

	Left Hand					Right Hand				
Op.	$T_{G.}$	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total	$T_{G.}$	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total
1	124	172	94	178	568	99	159	86	177	521
2	132	59	105	156	452	84	89	150	116	439
3	169	98	72	289	628	124	150	93	202	569
4	134	68	203	119	524	110	82	219	105	516
5	167	110	113	147	537	117	97	158	106	478
Av.	145	102	117	178	542	107	116	141	141	505

RECTANGULAR BOX BIN

Op.	$T_{G.}$	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total	$T_{G.}$	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total
1	221	157	80	224	682	188	181	82	169	620
2	127	93	136	157	513	162	85	218	42	507
3	182	185	124	206	697	195	193	71	234	693
4	276	85	136	154	651	165	120	225	115	625
5	241	166	148	184	739	20	269	161	158	608
Av.	209	137	125	185	656	146	170	151	144	611

TWO-HANDED WORK

PRE-POSITIONING SLIDE

Op.	$T_{G.}$ (R)*	$T_{G.}$ (L)**	$T_{T.L.}$ (R)	$T_{T.L.}$ (L)	$T_{R.L.}$ (R)	$T_{R.L.}$ (L)	$T_{T.E.}$ (R)	$T_{T.E.}$ (L)	Av. Total $\frac{R+L}{2}$
1	111	130	151	179	148	42	182	236	589
2	114	148	113	75	148	87	124	172	491
3	103	154	186	168	87	88	226	225	618
4	134	169	91	75	202	152	95	133	525
5	152	141	108	113	148	86	111	176	517
Av.	123	148	130	122	146	91	148	189	548

RECTANGULAR BOX BIN

Op.	$T_{G.}$ (R)*	$T_{G.}$ (L)**	$T_{T.L.}$ (R)	$T_{T.L.}$ (L)	$T_{R.L.}$ (R)	$T_{R.L.}$ (L)	$T_{T.E.}$ (R)	$T_{T.E.}$ (L)	Av. Total $\frac{R+L}{2}$
1	220	237	186	122	149	117	148	219	699
2	177	165	97	125	186	89	124	187	575
3	247	255	208	211	62	35	232	260	755
4	259	262	124	142	150	47	122	229	667
5	233	221	148	176	235	127	121	187	724
Av.	227	228	153	155	156	83	150	216	684

* (R) Therbligs of right hand.
** (L) Therbligs of left hand.

TABLE VI

RESULT SHEET

Medians selected on the basis of the total cycle time for the one-handed work and on the average of the total of both hands for the two-handed work. The averages of the medians are also shown. The parts grasped were 5 inch wooden cubes. Data are for five male operators.

Time in Thousandths of a Second

ONE-HANDED WORK

APRON WITH SPACERS

	Left Hand					Right Hand				
Op.	$T_{G.}$	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total	$T_{G.}$	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total
1	261	188	298	154	901	344	147	376	142	1009
2	277	90	310	101	778	301	114	268	164	847
3	354	94	155	227	830	290	155	238	158	841
4	330	128	296	204	958	337	162	221	214	934
5	260	139	183	217	799	312	139	214	128	793
Av.	296	128	248	181	853	317	143	263	161	885

APRON WITHOUT SPACERS

Op.	$T_{G.}$	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total	$T_{G.}$	$T_{T.L.}$	$T_{R.L.}$	$T_{T.E.}$	Total
1	283	96	324	100	803	205	160	326	121	812
2	247	109	180	113	649	165	124	222	121	632
3	222	104	216	121	663	96	139	233	153	621
4	291	151	187	210	839	249	207	209	195	860
5	162	142	221	95	620	164	181	167	140	652
Av.	241	120	226	128	715	176	162	231	146	715

TWO-HANDED WORK

APRON WITH SPACERS

Op.	$T_{G.}$ (R)*	$T_{G.}$ (L)**	$T_{T.L.}$ (R)	$T_{T.L.}$ (L)	$T_{R.L.}$ (R)	$T_{R.L.}$ (L)	$T_{T.E.}$ (R)	$T_{T.E.}$ (L)	Av. Total $\frac{R+L}{2}$
1	275	298	156	135	304	291	139	136	867
2	306	309	131	101	324	316	161	168	908
3	265	326	139	116	263	242	173	164	844
4	375	415	167	133	173	191	255	261	985
5	282	269	144	133	237	320	209	122	858
Av.	301	323	147	124	260	272	187	170	892

APRON WITHOUT SPACERS

Op.	$T_{G.}$ (R)*	$T_{G.}$ (L)**	$T_{T.L.}$ (R)	$T_{T.L.}$ (L)	$T_{R.L.}$ (R)	$T_{R.L.}$ (L)	$T_{T.E.}$ (R)	$T_{T.E.}$ (L)	Av. Total $\frac{R+L}{2}$
1	229	283	168	155	306	284	128	114	833
2	238	248	124	102	252	219	113	136	722
3	183	226	134	125	219	197	129	131	672
4	287	361	202	126	214	200	253	245	944
5	256	212	149	164	148	149	98	106	641
Av.	239	266	155	134	228	210	144	146	762

* (R) Therbligs of right hand.
** (L) Therbligs of left hand.

Effect of type of grasp as necessitated by bin
(*With plain square blocks only*)

The least time was required for release load when the part had been grasped from the pre-positioning bin. However, the release load, when the part had been grasped from the rectangular bin required, on the average, only 1% more time.

Effect of part grasped
(*From rectangular bin only*)

The least time was required for release load when the square block with protrusions was involved. A release load with the plain square block required, on the average, 3% more time.

5—IN REGARD TO TRANSPORT EMPTY TIME

Effect of primary conditions of involvement

The least time was required for transport empty when only the right hand was used. A transport empty with the left hand required, on the average, 46% more time, and a transport empty with both hands, 35% more time. However, since two transport emptys were performed simultaneously when the two hands were used, the time chargeable to each transport empty is 32% less than when only the right hand was used.

Effect of type of grasp as necessitated by bin
(*With plain square blocks only*)

The least time was required for a transport empty when it was followed by a grasp from the pre-positioning bins. A transport empty followed by a grasp from the rectangular bin required, on the average, 10% more time.

Effect of part grasped
(*From rectangular bin only*)

The least time was required for transport empty when the plain square blocks were involved in the subsequent grasp. The transport empty when followed by a grasp of a square block with protrusions required, on the average, 6% more time.

6—The data indicate that operators who were relatively efficient, as compared to other operators, at performing the motions of the task when using only the right hand were also relatively efficient in performing the task simultaneously with both hands. The correlation ratio between the total cycle times when working with the

right hand alone and simultaneously with both hands was +.86 over all types of grasp, types of block and all operators.

7—The data indicate that operators who were relatively efficient, as compared to other operators, at grasping the parts when using only the right hand, were also relatively efficient in performing the grasp simultaneously with both hands. The correlation ratio between the grasp time when working with only the right hand and the average grasp time per hand when working simultaneously with both hands was +.81 over all types of grasp, types of block, and all operators. (Grasp times for correlation were median grasp times taken on the basis of grasp time only.)

8—The conclusions 6 and 7 suggest that under the conditions observed in this investigation and with the operators tested, there was a good indication that a good "one-handed" operator was also a good "two-handed" operator, and a relatively poor "one-handed" operator was also a relatively poor "two-handed" operator. This suggests that the introduction of "two-handed", simultaneous work in place of less efficient "one-handed" work will not inconvenience any one operator very much more than another operator.

Block No. 2—One and One-half Inch Cubes

1—IN REGARD TO TOTAL CYCLE TIME

Effect of primary conditions of involvement

The least time was required for a total cycle when either the right or left hand alone was used, there being less than 1% difference between the two hands used singly. A total cycle with both hands working simultaneously required, on the average, 15% more time. However, since two cycles were performed simultaneously when the two hands were used, the time chargeable to each cycle was 42% less than when only the right hand was used.

Effect of type of grasp as necessitated by bin

The least time was required for a total cycle when the prepositioning bin was used. (With this bin, the block was always in the same position and location for grasping.) A total cycle containing a grasp from the rectangular bin required, on the average, 60% more time.

2—IN REGARD TO GRASP TIME

Effect of primary conditions of involvement

The least time was required for grasp when only the right

hand was used. A grasp with the left hand required, on the average, 5% more time, and a grasp with both hands (from two separate bins) 15% more time. However, since two grasps were performed simultaneously when the two hands were used, the time chargeable to each grasp was 42% less than when only the right hand was used.

Effect of type of grasp as necessitated by bin

The least time was required for grasp when the pre-positioning bin was used. A grasp from the rectangular bin required, on the average, 197% more time.

3—IN REGARD TO TRANSPORT LOADED TIME

Effect of primary conditions of involvement

The least time was required for transport loaded when only the left hand was used. A transport loaded with the right hand required, on the average, 8% more time, and a transport loaded with both hands, 37% more time. However, since two transport loadeds were performed simultaneously when the two hands were used, the time chargeable to each transport loaded was 31% less than when only the left hand was used.

Effect of type of grasp as necessitated by bin

The least time was required for transport loaded when the pre-positioning bin was used. A transport loaded from a rectangular bin required, on the average, 35% more time.

4—IN REGARD TO RELEASE LOAD TIME

Effect of primary conditions of involvement

The least time was required for release load when only the left hand was used. A release load with the right hand required, on the average, 97% more time, and a release load with both hands, 73% more time. However, since two release loads were performed simultaneously when the two hands were used, the time chargeable to each release load was 13% less than when only the left hand was used.

Effect of type of grasp as necessitated by bin

The least time was required for release load when the part had been grasped from the rectangular bin. When the part had been grasped from the pre-positioning bin, the release load required, on the average, 18% more time.

5—IN REGARD TO TRANSPORT EMPTY TIME

Effect of primary conditions of involvement

The least time was required for transport empty when only the right hand was used. A transport empty with the left hand required, on the average, 36% more time, and a transport empty with both hands, 25% more time. However, since two transport emptys were performed simultaneously when the two hands were used, the time chargeable to each transport empty was 37% less than when only the right hand was used.

Effect of type of grasp as necessitated by bin

The least time was required for a transport empty when it was followed by a grasp from a pre-positioning bin. A transport empty followed by a grasp from the rectangular bin required, on the average, 19% more time.

6—The data indicate that operators who were relatively efficient, as compared to other operators, at performing the motions of the task when using only the right hand were also relatively efficient in performing the task simultaneously with both hands. The correlation ratio between the total cycle times when working with the right hand alone and simultaneously with both hands was +.97 over all types of grasp and all operators.

7—The data indicate that operators who were relatively efficient, as compared to other operators, at grasping the parts when using only the right hand were also relatively efficient in performing the grasp simultaneously with both hands. The correlation ratio between the grasp time when working with only the right hand and the average grasp time per hand when working simultaneously with both hands was +.98 over all types of grasp, and all operators. (Grasp times for correlation were median grasp times selected on the basis of grasp time only.)

BLOCK NO. 3—TWO AND SEVEN-EIGHTH INCH CUBES

1—IN REGARD TO TOTAL CYCLE TIME

Effect of primary conditions of involvement

The least time was required for a total cycle when only the right hand was used. A total cycle with the left hand required, on the average, 7% more time, and a cycle with both hands, 10% more time. However, since two cycles were performed simultaneously when the two hands were used, the time chargeable to each cycle was 45% less than when only the right hand was used.

Effect of type of grasp as necessitated by bin

The least time was required for a total cycle when the pre-positioning bin was used. (With this bin, the block was always in the same position and location for grasping and was clear of other blocks on three sides.) A total cycle containing a grasp from the pre-positioning bin with a fixed corner in place at the bottom required, on the average, 22% more time. (With this fixed corner, the block was free on only one side while the other three sides were either in contact with other blocks or with the fixed corner which simulated adjacent blocks.)

2—IN REGARD TO GRASP TIME

Effect of primary conditions of involvement

The least time was required for grasp when only the right hand was used. A grasp with the left hand, required, on the average, 40% more time, and a grasp with both hands (from separate bins) 43% more time. However, since two grasps were performed simultaneously when the two hands were used, the time chargeable to each grasp was 28% less than when only the right hand was used.

Effect of type of grasp as necessitated by bin

The least time was required for grasp when the plain pre-positioning bin was used. A grasp from the pre-positioning bin with a fixed corner in place required, on the average, 50% more time.

3—IN REGARD TO TRANSPORT LOADED TIME

Effect of primary conditions of involvement

The least time was required for a transport loaded when only the left hand was used. A transport loaded with the right hand required, on the average, 20% more time, and a transport loaded with only the left hand, 17% more time. However, since two transport loadeds were performed simultaneously when the two hands were used, the time chargeable to each transport loaded was 41% less than when only the right hand was used.

Effect of type of grasp as necessitated by bin

The least time was required for transport loaded when the plain pre-positioning bin was used. A transport loaded from the pre-positioning bin with a fixed corner in place required, on the average, 34% more time.

4—IN REGARD TO RELEASE LOAD TIME

Effect of primary conditions of involvement

The least time was required for release load when both hands were used simultaneously. A release load with only the right hand required, on the average, 23% more time, and with only the left hand, 2% more time. However, since two release loads were performed simultaneously when the two hands were used, the time chargeable to each release load was 51% less than when only the left hand was used.

Effect of type of grasp as necessitated by bin

The least time was required for release load when the part had been grasped from the plain pre-positioning bin. When the part had been grasped from the pre-positioning bin with a fixed corner in place the release load required, on the average, 5% more time.

5—IN REGARD TO TRANSPORT EMPTY TIME

Effect of primary conditions of involvement

The least time was required for transport empty when only the right hand was used. A transport empty with the left hand required 27% more time, and a transport empty with both hands, 23% more time. However, since two transport emptys were performed simultaneously when the two hands were used, the time chargeable to each transport empty was 38% less than when only the right hand was used.

Effect of type of grasp as necessitated by bin

The least time was required for transport empty when it was followed by a grasp from the plain pre-positioning bin. When it was followed by a grasp from the pre-positioning bin with a fixed corner in place, it required, on the average, 5% more time.

6—The data indicate that operators who were relatively efficient, as compared to other operators, at performing the motions of the task when using only the right hand were also relatively efficient in performing the task simultaneously with both hands. The correlation ratio between the total cycle times when working with the right hand alone and simultaneously with both hands was +.98 over all types of grasp and all operators.

7—The data indicate that operators who were relatively efficient, as compared to other operators, at grasping the parts when using only the right hand were also relatively efficient in performing

the grasp simultaneously with both hands. The correlation ratio between the grasp time when working with only the right hand and the average grasp time per hand when working simultaneously with both hands was +.66 over all types of grasp and all operators. (Grasp times for correlation were median grasp times selected on the basis of grasp time only.)

Block No. 4—Five Inch Cubes

1—IN REGARD TO TOTAL CYCLE TIME

Effect of primary conditions of involvement

The least time was required for a total cycle when only the left hand was used. A total cycle with the right hand required, on the average, 2% more time, and a cycle with both hands, 6% more time. However, since two cycles were performed simultaneously when the two hands were used, the time chargeable to each cycle was 47% less than when only the right hand was used.

Effect of type of grasp as necessitated by supply apron

The least time was required for a total cycle when blocks were located on apron without spacers between blocks. (With this arrangement the block was always in the same position and location for grasping and was clear of other blocks on three sides. The blocks were grasped by placing the thumb and fingers on the two opposite clear sides.) A total cycle containing a grasp from an apron with spacers required, on the average, 22% more time. (With this arrangement the block was clear of other blocks on all sides. The block was grasped between the thumb on the front of the block and the fingers inserted between it and the next adjacent block.)

2—IN REGARD TO GRASP TIME

Effect of primary conditions of involvement

The least time was required for grasp when only the right hand was used. A grasp with the left hand, required, on the average, 9% more time, and a grasp with both hands, 14% more time. However, since two grasps were performed simultaneously when the two hands were used, the time chargeable to each grasp was 43% less than when only the right hand was used.

Effect of type of grasp as necessitated by supply apron

The least time was required for grasp when an apron without spacers was used. A grasp from an apron with spacers required, on the average, 38% more time.

3—IN REGARD TO TRANSPORT LOADED TIME

Effect of primary conditions of involvement

The least time was required for a transport loaded when only the left hand was used. A transport loaded with the right hand required, on the average, 23% more time, and a transport loaded with both hands, 14% more time. However, since two transport loadeds were performed simultaneously when the two hands were used, the time chargeable to each transport loaded was 43% less than when only the right hand was used.

Effect of type of grasp as necessitated by supply apron

The least time was required for transport loaded when an apron with spacers was used. A transport loaded from an apron without spacers required, on the average, 4% more time.

4—IN REGARD TO RELEASE LOAD TIME

Effect of primary conditions of involvement

The least time was required for release load when the left hand was used. A release load with only the right hand required, on the average, 4% more time, and a release load with both hands 3% more time. However, since two release loads were performed simultaneously when the two hands were used, the time chargeable to each release load was 44% less than when only the left hand was used.

Effect of type of grasp as necessitated by supply apron

The least time was required for release load when the part had been grasped from an apron without spacers. When the part had been grasped from an apron with spacers, the release load required, on the average, 15% more time.

5—IN REGARD TO TRANSPORT EMPTY TIME

Effect of primary conditions of involvement

The least time was required for transport empty when only the

right hand was used. A transport empty with the left hand required 1% more time, and a transport empty with both hands, 5% more time. However, since two transport emptys were performed simultaneously when the two hands were used, the time chargeable to each transport empty was 47% less than when only the right hand was used.

Effect of type of grasp as necessitated by supply apron

The least time was required for transport empty when it was followed by a grasp from an apron without spacers. When it was followed by a grasp from an apron with spacers, it required, on the average, 24% more time.

PART III

POSITIONING SMALL PARTS[10]

by

RALPH M. BARNES
JOHN M. MACKENZIE
MARVIN E. MUNDEL

Object.—The object of this study was to determine the effect of the size and shape of openings into which one-half inch cubes were disposed, A, when only the right hand was used, and B, when both hands were used. Seven pairs of masks were used to furnish the experimental conditions corresponding to the classification of restrictions of disposal areas into which the blocks were placed.

The operation for this study consisted of picking up (*select and grasp*) a block from a bin placed on the table, carrying it (*transport loaded*) to an opening in the table top directly in front of the operator, disposing of it (*position and release load*) into the opening, and moving (*transport empty*) the hand back to the bin for another block.

The masks containing the openings for the disposal of the blocks were arranged in order of difficulty insofar as could be estimated. See Fig. 21. The relative amount of restriction in position was determined by (1) the degree to which the shape and size of the hole affected the positioning of the block in the hole, see Figs. 22 and 23; and (2) by the minimum clearance between the block and the sides of the slot or opening in the mask.

Parts Used.—One-half inch wood cubes were made of walnut carefully sanded to $0.50 \pm .01$ inch across each face. Seven pairs of masks were constructed from "pressboard" with right parallelograms cut in them with dimensions as shown in Fig. 21. All dimensions were held within $\pm .01$ inch. The masks fitted over

[10]A thesis by John M. MacKenzie submitted in partial fulfillment of the requirements for the degree of Master of Science in the Department of Mechanical Engineering, in the Graduate College of the State University of Iowa, August, 1939.

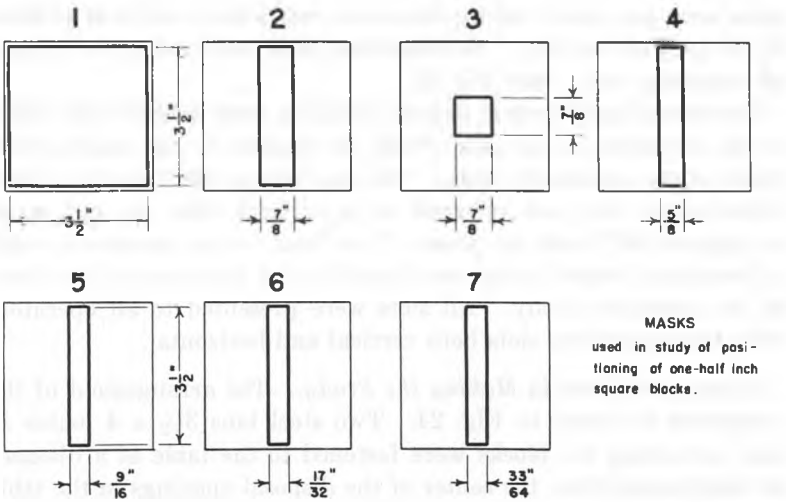

Fig. 21. Masks used in study of positioning and releasing one-half inch wood blocks.

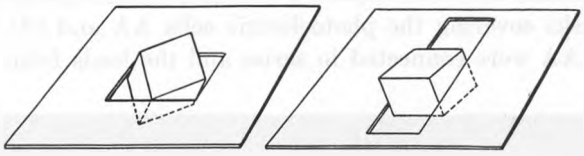

Fig. 22. Mask Nos. 1, 2, and 3. Size of opening is larger than the diagonal of the cube. Block may be disposed into opening in any position relative to the sides of the opening in the mask.

Fig. 23. Mask Nos. 4, 5, 6, and 7. The width of the slot is such that the block must be carefully positioned with respect to the sides of the slot in the mask.

3½ inch square holes cut in the table top as shown in Fig. 24.

The 3½ inch square hole was selected as the easiest because of the wide clearances. The 3½ x ⅞ inch rectangular slot was selected for No. 2 because the clearance was decreased in only one direction. The ⅞ x ⅞ inch square hole was No. 3 because the clearance was reduced in both directions. None of the first three masks restricts the position of the block in the hole because no dimension was less than the diagonal of the cube. See Fig. 22.

The 3½ x ⅝ inch rectangular slot was selected as No. 4. It represented a large increase in clearance in one direction over No. 3, and only a small decrease in the other direction but the dimen-

sions were now such that the block was restricted in a plane parallel to the axis of the slot. The remaining slots were ranked on a basis of clearance only. See Fig. 23.

Horizontal and vertical slots in masks as used in this study refer to the direction of the axis of the slot relative to the plane of the front of the operator's body. The slot was at all times in a horizontal plane, but was referred to as vertical when its axis made an angle of 90° with the plane of the front of the operator's body, or horizontal when its axis was parallel with the plane of the front of the operator's body. All slots were presented to all operators with the axes of the slots both vertical and horizontal.

Equipment Used in Making the Study.—The arrangement of the workplace is shown in Fig. 24. Two steel bins 3½ x 4 inches in size containing the blocks were fastened to the table at a distance of eight inches from the center of the disposal openings in the table top.

Each of two projectors was placed in such a manner that its beam of light passed over the top of a bin and fell on horizontal slots in the masks covering the photoelectric cells AA and CC, Fig. 16. The cells AA were connected in series and the leads from the cells

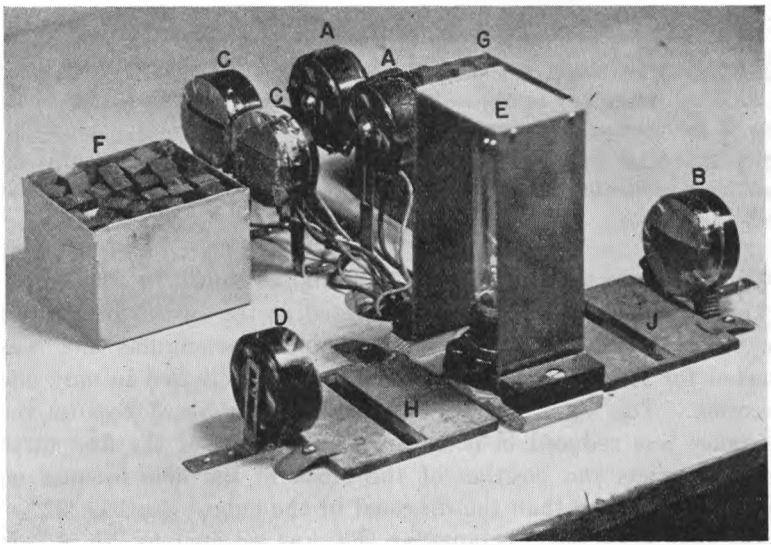

Fig. 24. Arrangement of the workplace. A, B, C, D—photoelectric cells; E, light source for cells B and D; F, G,—bins; H, J,—masks with slots vertical.

carried to relay A, and similarly from cells CC to relay C. A projector bulb in a shield spread light across the position and release load areas, lighting the faces of cells B and D, Fig. 16.

The kymograph was used for recording time. Two rollers driven at constant speed drew a strip of adding machine paper under a set of pencils actuated by solenoids and controlled through the photo cell relays. The pencils remained stationary tracing a straight line on the paper until the beam of light on the cell was interrupted; then the solenoid caused the pencil to move about three-eighths of an inch, leaving a jog in the line. When the light again fell on the photo cell the current in the solenoid was interrupted by the relay and a spring returned the pencil to its original position.

The time intervals were recorded by the kymograph on adding machine paper moving at 31.9 inches per second. A sample kymograph record is shown in Fig. 25(a). The first jog in line A was caused by the operator's hand breaking the beam of light over the bin of blocks. The pencil remained displaced as long as the beam was interrupted, but as soon as the operator's hand left the bin, the beam of light again fell on the photo cell and the pencil was released, returning to its original position and making the second jog in line A. The distance between the first and second jogs was proportional to the time required for the therbligs select and grasp.

As the operator carried the block into the release area his hand interrupted the light from the projector bulb, causing pencil B to make the first jog in line B. The distance between the second jog in line A and the first jog in line B was proportional to the time required for the therblig transport loaded.

When the hand left the positioning area the light again fell on the photo cell and pencil B returned to its original position, making the second jog in line B. The distance between the first and second jogs in line B was proportional to the time required for the therbligs position and release load.

The hand returned empty to the bin, the cycle being completed when the hand again interrupted the beam over the bin, making the third jog in line A. The distance between the second jog in line B and the third jog in line A was proportional to the time for the therblig transport empty.

The time for each individual therblig was measured and recorded. The analysis of two-handed work included the measurement of the

leads of one hand over the other. Fig. 25(b) shows the leads of the hands for the various therbligs as they appear in a typical kymograph record for two-handed work. When the right hand lead the left the lead was recorded as plus; when the left hand lead the right, it was recorded as minus.

All recorded data were checked by remeasurement of the kymograph record. Fifteen consecutive cycles were then selected from each of the two runs, giving a total of thirty cycles for each condition of the study. The data for two-handed work were given a second check by the rule that the difference of the two hands for any therblig plus the lead must equal the following lead. This can be seen on the sample kymograph record shown in Fig. 25(b).

Total cycle times for the thirty cycles were arrayed for right-handed work only. Arrays for two-handed work were based on one half the sum of the times for the two hands. The two central totals in the distribution were selected. The complete cycle corresponding to each central total was recorded on the array sheet.

This procedure resulted in the selection of typical values for the

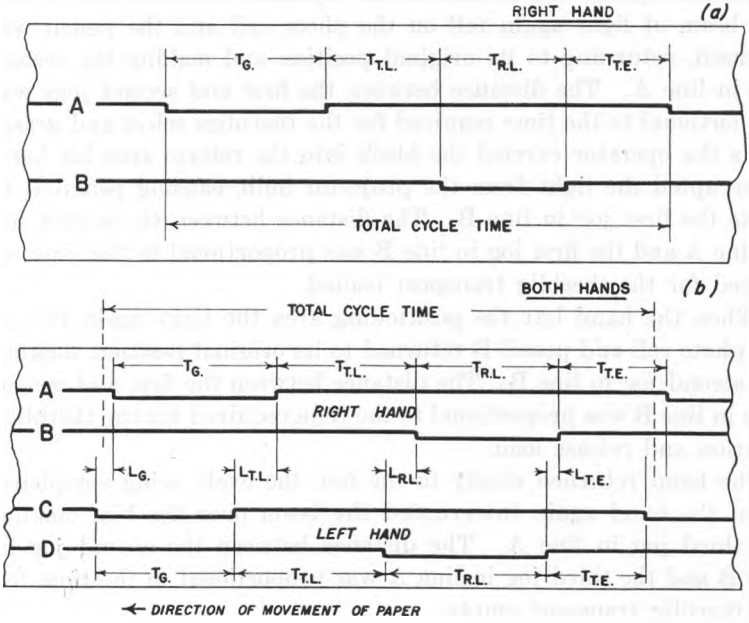

Fig. 25. Reproduction of one cycle of the record made by solenoid operated pencils on the kymograph when the operator was working (a) with his right hand only, (b) with both hands.

therbligs that are not necessarily median values of the therbligs. This is justified by the fact that the therbligs in any one cycle are interrelated.[11] Any cycle made up of medians for each therblig might not display this interrelation and, hence, it might not be typical of all cycles performed under that condition for that operator.

It is upon these typical cycles that all graphs, tables and conclusions were based.

Procedure.—Five male operators were used as subjects for this study. All of the operators selected were right handed and accustomed to the use of small tools.

The operation was described to the subject but no reference was made as to the purpose of the study or as to the difficulty of the tests. The operator was instructed: (1) to carry the block to the disposal opening before releasing it, that is, he was not to slide the block to the opening or to throw it into the opening, but was to carry it all the way; and (2) to make every effort to see that the block dropped through the hole before the hand left the work area.

The operator practiced twenty-five cycles with the right hand and then twenty-five cycles with both hands on each of the twelve conditions. The conditions were taken in the order of assumed difficulty: mask 1; mask 2 vertical; mask 2 horizontal; mask 3; mask 4 vertical; mask 4 horizontal, etc. No kymograph records were made during the practice period.

Following the practice period all masks were removed and the operator practiced fifteen cycles on condition one (Mask No. 1) with the right hand only. The operator was instructed to count to three after the kymograph was started, and then to perform twenty cycles as rapidly as possible. This procedure was repeated for both hands. Mask No. 2 was placed over the hole with the slot perpendicular to the plane of the front of the operator's body (referred to as run 2V). The operator again practiced fifteen cycles and performed twenty cycles as fast as possible with the right hand alone and then with both hands together. The mask was then rotated through ninety degrees so that the slot was parallel to the plane of the front of the operator's body (referred

[11] Barnes, Ralph M., and Mundel, Marvin E., "Studies of Hand Motions and Rhythm Appearing in Factory Work," p. 30, Bull. 12, *University of Iowa Studies in Engineering*, 1938.

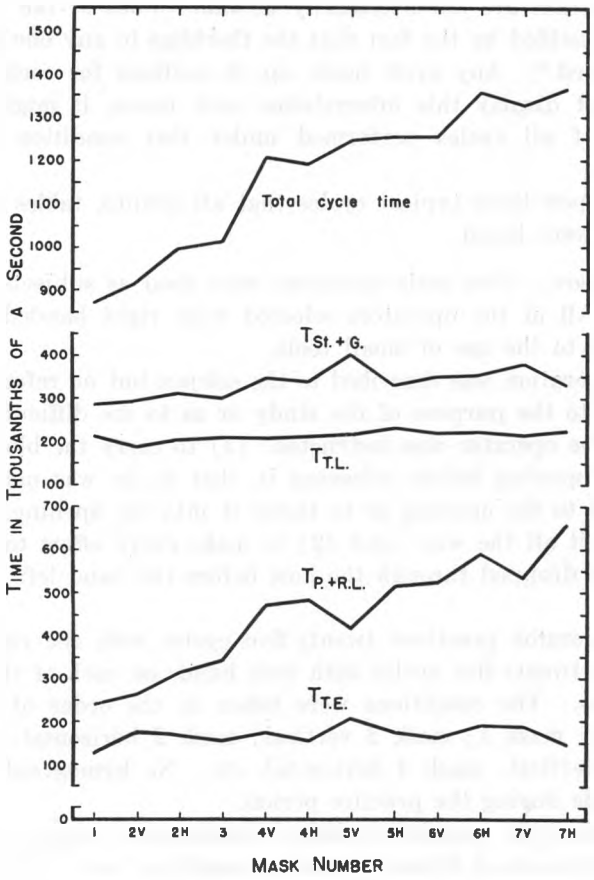

Fig. 26. Curves showing the effect of twelve different conditions of positioning and releasing blocks on the therbligs *select* and *grasp, transport loaded, position* and *release load, transport empty,* and on the total cycle time for right-handed work. Average median values for five male operators.

to as run 2H) and the previous routine repeated. Only one run was performed with the masks with square holes. When runs for all conditions had been made, the order of performance was reversed, that is the conditions were taken in the following order: 7H, 7V, 6H, 6V, 5H, 5V, etc. Two hands were used first with each condition, then the right hand alone was used. Runs were made for all conditions back to the primary condition so as to eliminate the effects of acquired skill.

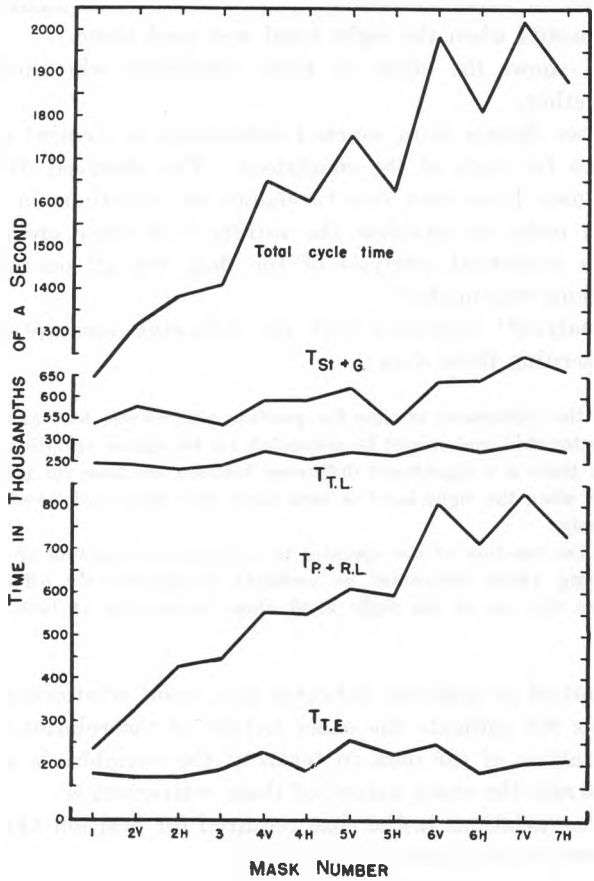

Fig. 27. Curves showing the effect of twelve different conditions of positioning and releasing blocks on the therbligs *select* and *grasp, transport loaded, position* and *release load, transport empty,* and on the total cycle time for two-handed work. Average median values for five male operators.

Results.—The two central cycles selected from the array of total cycle times were averaged to obtain median values of the total cycle time. The times for the individual elements of these two central cycles were averaged to obtain the elements of the median cycle. These elements and total cycle times were averaged for the five operators to obtain the typical element times and total cycle time for each of the conditions of restriction of position considered.

Fig. 26 shows the effect of each of the disposal areas arranged

in the order of assumed difficulty, upon the time required for each of the elements when the right hand was used alone.

Fig. 27 shows the effect of these conditions when using both hands together.

These two figures show marked differences in element and total cycle times for each of the conditions. The observed differences, however, may have been due to chance or variations in operator skills. In order to establish the validity[12] of these observed differences a statistical analysis of the data for all operators and all conditions was made.[13]

This analysis[14] indicated that the following assumptions were valid concerning these data:

1. That the differences in time for position plus release load are independent of operator skill and cannot be accounted for by chance variations.
2. That there is a significant difference between the time for position plus release load when the right hand is used alone and when both hands are used simultaneously.
3. That the reaction of the operator to a change in direction of restriction of positioning (slots horizontal or vertical) is significantly affected by a change from the use of the right hand alone to the use of both hands together.

This method of analysis indicates that valid relationships exist, but it does not indicate the exact nature of the relationships. A careful analysis of the data in terms of the variables is necessary to demonstrate the exact nature of these relationships.

Since the variations in the time required for position plus release load are not due to chance, we may safely assume that these variations are due to real differences in restriction of positioning between the various masks.

Figs. 26 and 27 show that merely shifting the axis of the slot will materially alter the position plus release load time and total cycle time, other conditions being the same. A comparison of the two figures also shows that two-handed work requires more time

[12]The words valid or significant as applied here mean that the relations described could occur due to chance only once in one hundred or more times.

[13]Analysis of variance, from "Statistical Methods for Research Workers," by Fisher, 6th Ed. 1936, as presented in "Statistical Methods in Educational Research" by Lindquist, Limited edition, University of Iowa, 1939.

Also, "The Design of Experiments" by Fisher, 2nd ed. 1937, Oliver and Boyd, London.

[14]Statistical analysis of variance made by Marvin E. Mundel.

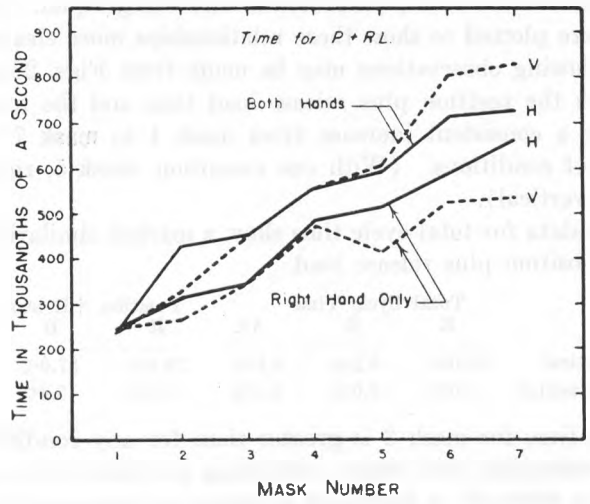

Fig. 28. Curves showing time for *position* and *release load* for all conditions.

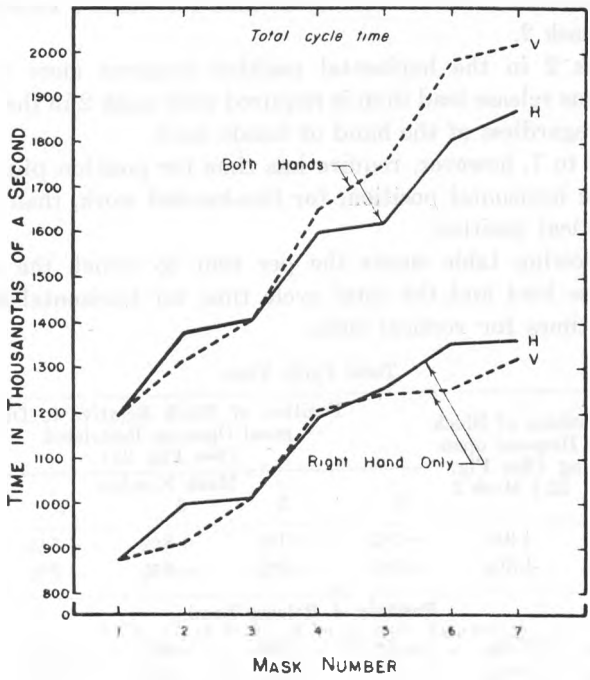

Fig. 29. Curves showing *total cycle time* for all conditions.

than single-handed work, other conditions being equal. Figs. 28 and 29 were plotted to show these relationships more clearly.

The following observations may be made from Figs. 28 and 29:

1. Both the position plus release load time and the total cycle time show a consistent increase from mask 1 to mask 7 for any given set of conditions. (With one exception, mask 5, right hand only, slot vertical).

2. The data for total cycle time show a marked similarity to the time for position plus release load.

	Total Cycle Time			Position + Release Load		
	R	B	Av.	R	B	Av.
Mask 2 Vertical	10.0%	8.2%	9.1%	28.4%	37.0%	32.7%
Mask 2 Horizontal	1.0%	2.0%	1.5%	8.9%	5.6%	7.2%

3. The time for mask 3 is greater than for any condition with mask 2, indicating that when positioning is restricted in two directions the difficulty is increased, although the minimum clearance is the same for mask 2 (see Fig. 21) as for mask 3. See table below.

The following table shows the per cent by which the position plus release load time and the total cycle time for mask 3 exceeded the time for mask 2.

4. Mask 2 in the horizontal position requires more time for position plus release load than is required with mask 2 in the vertical position, regardless of the hand or hands used.

Masks 4 to 7, however, require less time for position plus release load in the horizontal position, for two-handed work, than they do in the vertical position.

The following table shows the per cent by which the position plus release load and the total cycle time for horizontal slots exceeds the times for vertical slots:

	Position of Block to Disposal opening (See Fig. 22.) Mask 2	Position of Block Relative to Disposal Opening Restricted (See Fig. 23) Mask Number				
		4	5	6	7	Av.
Total Cycle Time						
Right Hand	+9%	−1%	+1%	+8%	+5%	+5%
Both Hands	+5%	−3%	−7%	−8%	−7%	−4%
Position + Release Load						
Right Hand	+18%	+2%	+23%	+12%	+27%	+16%
Both Hands	+30%	0%	− 2%	−11%	−12%	+ 1%

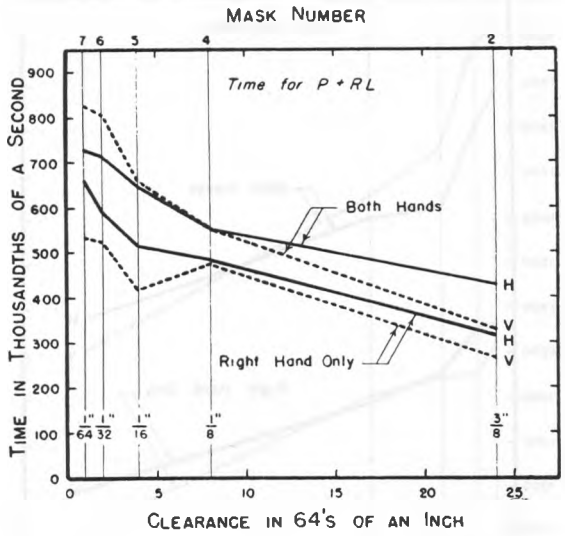

Fig. 30. Curves showing time for *position* and *release load* for all slots.

It will be noticed that the percentages in the above table do not show any definite trend which indicates that the effects of differences in clearances and direction of the axis of the slots are independent of each other insofar as slots 4 to 7 inclusive are concerned.

Figs. 30 and 31 were plotted to show the relation of the position plus release load time and total cycle time to minimum clearance for the various conditions. Slots only were considered here because of the added variable introduced by the restriction in two directions of mask 3.

The following observations may be made concerning Figs. 30 and 31:

1. The greatest rate of increase in time for position plus release load occurs between masks 5 and 6.

2. In general the increase in position plus release load time and total cycle time is relatively small per unit decrease in clearance until the clearance is reduced to 1/16″; the rate of increase then is rapid to 1/32″. From 1/32″ to 1/64″, however, the rate is somewhat less.

The following table shows the per cent by which the position plus

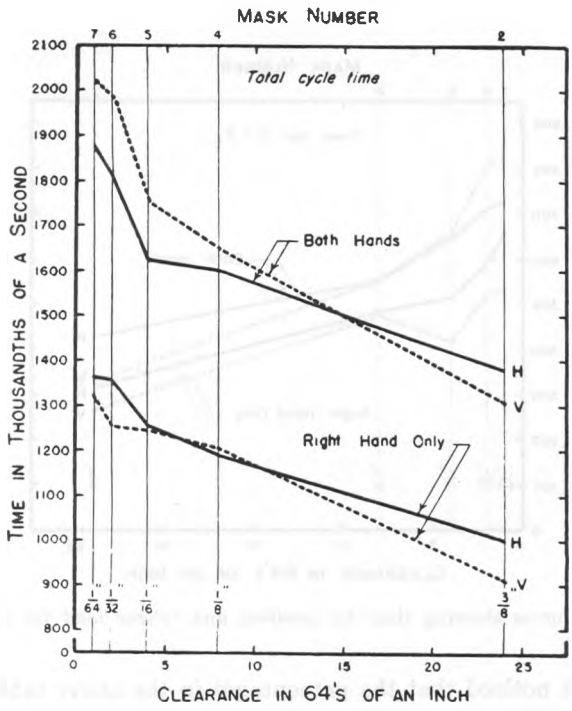

Fig. 31. Curves showing total cycle time for all slots.

Position + Release Load Time

	Mask Number				
	2	4	5	6	7
Right hand Slot vertical	10	93	73	117	122
Right hand Slot horizontal	30	100	113	142	181
Both hands Slot vertical	41	137	161	245	256
Both hands Slot horizontal	83	137	156	205	213

Total Cycle Time

	Mask Number				
	2	4	5	6	7
Right hand Slot vertical	5	39	43	44	52
Right hand Slot horizontal	15	37	44	56	59
Both hands Slot vertical	10	38	47	66	69
Both hands Slot horizontal	16	34	36	51	57

release load and the total cycle time for masks 2, 4, 5, 6, and 7 exceeds the times for mask 1.

3. There is a distinct difference in the time required, for both position plus release load time and for total cycle time, when the right hand only is used as compared with the time required for both hands.

The following table shows the per cent by which the time for the right hand exceeds the time for both hands for position plus release load and for total cycle time.

Total Cycle Time

	Mask Number							
	1	2	3	4	5	6	7	Av.
Slot vertical	+37	+42	+40	+37	+41	+56	+52	+44
Slot horizontal	+37	+38	+40	+34	+29	+33	+35	+35

Position + Release Load

	Mask Number							
	1	2	3	4	5	6	7	Av.
Slot vertical	—4%	+23	+32	+16	+45	+53	+55	+31
Slot horizontal	—4%	+36	+32	+14	+16	+21	+ 7	+17

Conclusions.—There are four factors affecting the position plus release load time under the conditions of this study.

a. Minimum clearance between the block and any two edges of the disposal opening.

b. The number of hands used in performing the task.

c. The direction of restriction (that is the axis of the slot in the mask) relative to the plane of the front of the operator's body.

d. The restriction upon the position of the block in the hand relative to the shape of the disposal area.

These four factors are interrelated, and statements concerning one must be qualified in terms of the remaining three.

1. In general, for a given set of conditions, a decrease in the minimum clearance between the block and the disposal opening causes an increase in the position plus release load time.

2. For a given set of conditions, the time required for position plus release load when using both hands is 25 per cent greater than the time required when using one hand alone. However, two blocks are being carried instead of one.

3. The position plus release load time is greater for slots horizontal than for slots vertical if the minimum clearance does not restrict the position of the block relative to the shape of the disposal opening slots. If the right hand alone is used, the position plus release load time is greater, in all cases, for slots horizontal than for slots vertical.

4. The position plus release load time is greater for slots vertical than for slots horizontal when both hands are used and when the minimum clearance restricts the position of the block relative to the disposal opening; slots 4, 5, 6, and 7.

RESULT SHEET

Medians selected on the basis of total cycle time (i.e., total time for select and grasp; transport loaded; position and release load; and transport empty) for five male operators. Time in Thousandths of a Second

TABLE I - 3 1/2" Square

Both Hands

Therblig	Left Hand Operator 1	2	3	4	5	Mean	Therblig	Right Hand Operator 1	2	3	4	5	Mean
St.+G.	574	392	591	653	737	589	St.+G.	305	303	627	552	635	484
*	-163		-45	-104			*		+17	+32		+21	+23
T.L.	195	168	197	341	226	225	T.L.	314	229	210	284	287	265
			-5			-5		+107	+105		+55	+122	+97
P.+R.L.	233	270	278	130	114	205	P.+R.L.	278	366	248	175	236	261
	-12		-16			-14			+44		+113	+62	+73
T.E.	145	194	132	169	227	173	T.E.	291	114	158	199	152	183
	-57	-51			-60	-56				+15	+07		+41
Total	1146	1024	1197	1293	1304	1192	Total	1188	1015	1242	1210	1310	1192

Right Hand Only

St.+G.							St.+G.	156	220	311	352	398	287
T.L.							T.L.	324	138	228	174	204	213
P.+R.L.							P.+R.L.	160	187	336	298	229	242
T.E.							T.E.	149	100	158	111	120	128
Total							Total	789	846	1033	935	951	870

TABLE II - 7/8" x 3 1/2" Slot Vertical

Both Hands

St.+G.	711	495	633	494	567	580	St.+G.	473	558	726	442	617	563
	-54		-19			-36			+46		+10	+37	+31
T.L.	195	191	274	263	241	233	T.L.	309	167	217	342	204	248
		-19	-112		-13	-48		+185			+63		+124
P.+R.L.	250	302	288	486	283	322	P.+R.L.	328	374	262	396	326	337
			-54	-16		-35		+70	+ 3			+25	+33
T.E.	160	172	182	181	199	179	T.E.	138	112	225	147	168	158
	-9	-66	-28		-17	-30					+75		+75
Total	1416	1159	1378	1434	1389	1313	Total	1248	1212	1430	1327	1315	1306

Right Hand Only

St.+G.							St.+G.	257	213	351	356	305	296
T.L.							T.L.	203	169	193	179	175	184
P.+R.L.							P.+R.L.	224	270	235	337	268	267
T.E.							T.E.	146	193	145	209	160	171
Total							Total	830	845	924	1081	908	917

TABLE III - 7/8" x 3 1/2" Slot Horizontal

Both Hands

St.+G.	705	505	509	549	603	574	St.+G.	608	509	442	598	524	536
	-50		-118			-84			+37		+ 8	+46	+30
T.L.	175	211	265	275	186	223	T.L.	226	221	224	245	282	239
			-63	-43		-86		+47	+32			+124	+68
P.+R.L.	383	408	434	418	351	399	P.+R.L.	438	480	471	411	482	456
	-2		-12	- 9		-8			+21			+28	+24
T.E.	146	210	172	196	216	188	T.E.	106	130	204	164	143	148
	-56	-51	-50	-35	-103	-59							
Total	1410	1334	1380	1438	1356	1383	Total	1378	1341	1342	1418	1431	1381

Right Hand Only

St.+G.							St.+G.	294	240	291	339	401	313
T.L.							T.L.	215	179	223	195	201	202
P.+R.L.							P.+R.L.	312	331	182	481	272	315
T.E.							T.E.	174	132	244	162	141	170
Total							Total	995	882	940	1177	1015	1000

TABLE IV - 7/8" Square

Both Hands

St.+G.	581	422	507	560	703	554	St.+G.	452	283	467	539	633	475
		-75	-75			-75		+26				+10	+18
T.L.	175	221	242	261	231	226	T.L.	312	259	229	259	312	274
		-65	-35			-50		+156			+21	+79	+85
P.+R.L.	395	487	429	466	364	428	P.+R.L.	529	567	369	481	428	474
					-1	-1		+18	+27	+25	+21		+23
T.E.	132	209	179	202	231	190	T.E.	114	192	348	197	124	195
	-42	-48			-64	-62				+38	+ 6		+22
Total	1283	1340	1357	1489	1529	1398	Total	1407	1402	1414	1476	1497	1418

Right Hand Only

St.+G.							St.+G.	212	165	314	323	465	299
T.L.							T.L.	193	202	203	274	171	208
P.+R.L.							P.+R.L.	321	407	273	455	260	343
T.E.							T.E.	176	94	166	215	141	158
Total							Total	902	869	976	1267	1037	1010

* Lead: sign is negative if left hand leads at beginning of therblig, positive if right hand leads.

RESULT SHEET

Medians selected on the basis of total cycle time (i.e., Total time for select and grasp; Transport loaded; position and release load; and transport empty) for five male operators.
Time in Thousandths of a Second

TABLE V - 5/8" x 3 1/2" Slot Vertical

Both Hands

Therblig	Left Hand Operator 1	2	3	4	5	Mean	Therblig	Right Hand Operator 1	2	3	4	5	Mean
St.+G.	645	376	783	554	763	624	St.+G.	495	318	568	651	773	561
*	-33	-27	-24		-22	-26	*				+131		+131
T.L.	190	265	296	244	243	248	T.L.	305	278	455	255	231	305
					-32	-32		+118	+30	+188	+ 36		+93
P.+R.L.	449	687	487	749	348	544	P.+R.L.	492	608	575	667	463	562
					-21	-21		+3	+17	+ 29	+24		+18
T.E.	178	176	203	165	477	240	T.E.	163	176	262	196	284	216
	-39		-58		-138	-78			+ 96		+106		+101
Total	1462	1504	1769	1712	1811	1696	Total	1455	1380	1861	1769	1751	1644
							Right Hand Only						
St.+G.							St.+G.	277	296	247	410	502	346
T.L.							T.L.	224	211	225	198	189	209
P.+R.L.							P.+R.L.	496	446	539	481	419	476
T.E.							T.E.	112	141	232	244	144	175
Total							Total	1109	1094	1244	1333	1254	1206

TABLE VI - 5/8" x 3 1/2" Slot Horizontal

Both Hands

St.+G.	762	522	496	618	638	607	St.+G.	560	357	637	511	805	574
	-104	-64	-92	-101		-90						+10	+10
T.L.	192	237	423	285	344	296	T.L.	288	294	201	293	207	257
			-235		-155	-195		+97	+102		+6		+68
P.+R.L.	500	516	446	707	497	533	P.+R.L.	575	658	454	717	458	572
			-13	-1	-18	-11		+1	+46				+24
T.E.	177	191	185	177	179	182	T.E.	186	159	228	208	134	183
	-75	-96	-29	-12		-53						+21	+21
Total	1631	1465	1544	1787	1658	1618	Total	1609	1469	1520	1729	1604	1586
							Right Hand Only						
St.+G.							St.+G.	306	267	329	341	453	339
T.L.							T.L.	173	231	185	299	166	211
P.+R.L.							P.+R.L.	494	453	556	545	380	486
T.E.							T.E.	137	121	186	207	134	157
Total							Total	1110	1073	1256	1392	1133	1193

TABLE VII - 9/16" x 3 1/2" Slot Vertical

Both Hands

St.+G.	573	406	803	761	779	664	St.+G.	480	418	667	610	702	575
	-12	-8	-130	-103		-63						+35	+35
T.L.	246	302	231	308	250	267	T.L.	282	277	213	302	315	278
		-20				-20		+79		+5	+89	+113	+61
P.+R.L.	603	667	489	568	539	573	P.+R.L.	687	795	516	761	455	643
								+44	+4	+23	+82	+49	+40
T.E.	182	213	188	208	320	222	T.E.	151	111	435	265	487	290
	-40	-123		-138		-100						+134	+134
Total	1604	1589	1710	1845	1888	1727	Total	1600	1602	1811	1938	1959	1786
							Right Hand Only						
St.+G.							St.+G.	310	377	259	496	565	401
T.L.							T.L.	196	218	228	235	206	217
P.+R.L.							P.+R.L.	325	443	387	559	379	419
T.E.							T.E.	384	137	227	156	136	208
Total							Total	1215	1175	1101	1446	1286	1245

TABLE VIII - 9/16" x 3 1/2" Slot Horizontal

Both Hands

St.+G.	670	328	651	600	492	548	St.+G.	589	846	305	597	459	559
	-26		-124	-90		-80			+390			+155	+273
T.L.	197	333	229	272	229	252	T.L.	230	212	422	221	375	292
		-127		-86		-107		+52		+223		+190	+155
P.+R.L.	546	527	507	602	752	587	P.+R.L.	586	619	500	648	699	605
		-6		-36		-21		+23		+30		+41	+31
T.E.	163	188	180	189	234	191	T.E.	155	135	289	269	237	217
		+98		-82		-90		+8		+37		+94	46
Total	1576	1376	1567	1663	1707	1578	Total	1534	1812	1516	1735	1770	1673
							Right Hand Only						
St.+G.							St.+G.	351	272	361	317	350	330
T.L.							T.L.	242	200	294	245	173	231
P.+R.L.							P.+R.L.	493	567	398	576	540	515
T.E.							T.E.	171	149	255	180	135	178
Total							Total	1257	1188	1304	1318	1198	1254

* Lead: sign is negative if left hand leads at beginning of therblig, positive if right hand leads.

RESULT SHEET

Medians selected on the basis of total cycle time (i.e., Total time for select and grasp; transport loaded; position and release load; and transport empty) for five male operators. Time in Thousandths of a Second

TABLE IX - 17/32" x 3 1/2" Slot Vertical

Both Hands

Therblig	Left Hand Operator 1	2	3	4	5	Mean	Therblig	Right Hand Operator 1	2	3	4	5	Mean
St.+G.	750	660	630	807	723	714	St.+G.	757	530	417	416	663	557
*	-22	-29	-37	-199		-72	*					+62	+62
T.L.	306	259	234	277	278	271	T.L.	384	337	264	368	247	320
	-30					-30			+101	+176	+192	+122	+118
P.+R.L.	710	814	846	592	883	769	P.+R.L.	626	867	725	808	1169	839
	-108					-108			+23	+146	+101	+153	+ 85
T.E.	152	214	276	181	226	210	T.E.	155	129	682	351	125	288
	-24	-30		-165	-132	-70				+269			+269
Total	1918	1947	1986	1857	2110	1946	Total	1922	1864	2084	1943	2204	1983
							Right Hand Only						
St.+G.							St.+G.	278	192	305	376	598	350
T.L.							T.L.	206	247	176	271	199	220
P.+R.L.							P.+R.L.	535	559	551	532	449	525
T.E.							T.E.	152	159	208	199	91	162
Total							Total	1171	1157	1240	1378	1117	1257

TABLE X - 17/32" x 3 1/2" Slot Horizontal

Both Hands

St.+G.	677	604	769	730	637	683	St.+G.	715	514	814	472	466	596
		-46	-72	-49	-10	-44		+168					+168
T.L.	174	240	306	226	230	235	T.L.	401	256	211	395	304	313
			-116			-116		+204	+38		+210	+159	+152
P.+R.L.	546	779	577	805	690	679	P.+R.L.	593	749	624	914	859	748
	-18		-21			-20			+27		+41	+86	+51
T.E.	163	188	179	154	178	172	T.E.	172	188	281	179	129	189
	-55		-67	-68	-81	-70			+57				+57
Total	1559	1611	1841	1915	1746	1770	Total	1882	1707	1929	1960	1759	1847
							Right Hand Only						
St.+G.							St.+G.	254	143	528	458	386	354
T.L.							T.L.	204	252	193	277	184	222
P.+R.L.							P.+R.L.	443	662	512	539	796	590
T.E.							T.E.	225	172	241	203	116	191
Total							Total	1126	1230	1475	1477	1482	1468

TABLE XI - 33/64" x 3 1/2" Slot Vertical

Both Hands

St.+G.	718	665	1068	542	835	765	St.+G.	694	414	847	298	855	622
		-54	-189	-207		-150		+40				+52	+46
T.L.	280	232	265	357	224	271	T.L.	307	423	229	425	205	318
								+64	+196	+33	+36	+78	+81
P.+R.L.	744	626	690	1122	878	812	P.+R.L.	794	708	650	1180	893	845
				-31		-31		+36	+6	+68		+88	+39
T.E.	134	257	177	163	151	176	T.E.	122	176	465	261	125	230
	-14	-75		-89		-59				+109		+32	+70
Total	1876	1780	2200	2184	2088	2024	Total	1917	1721	2191	2164	2078	2015
							Right Hand Only						
St.+G.							St.+G.	223	289	478	345	564	379
T.L.							T.L.	240	223	178	264	181	217
P.+R.L.							P.+R.L.	467	509	415	640	650	536
T.E.							T.E.	196	187	268	184	116	190
Total							Total	1126	1208	1340	1433	1511	1323

TABLE XII - 33/64" x 3 1/2" Slot Horizontal

Both Hands

St.+G.	784	406	717	576	656	628	St.+G.	846	496	761	780	579	692
		-103				-103		+63		+18	+56	+18	+39
T.L.	263	349	216	391	195	283	T.L.	299	237	212	316	284	270
		-192	-24	-147	-93	-114		+1					+1
P.+R.L.	562	665	788	937	735	737	P.+R.L.	572	559	554	823	1097	721
	-36	-82	-20	-71		-52						+5	+5
T.E.	153	203	134	229	439	231	T.E.	125	310	237	168	111	189
	-46			-9	-358	-137			+24	+214			+119
Total	1762	1622	1855	2133	2025	1879	Total	1842	1602	1764	2087	2071	1873
							Right Hand Only						
St.+G.							St.+G.	346	264	356	285	396	329
T.L.							T.L.	248	221	166	313	183	226
P.+R.L.							P.+R.L	556	644	641	796	662	680
T.E.							T.E.	101	154	188	171	120	147
Total							Total	1252	1284	1351	1565	1361	1382

* Lead: sign is negative if left hand leads at beginning of therblig, positive if right hand leads.

TABLE XIII

RESULT SHEET

Summary of Means of Selected Median Cycles

Time in Thousandths of a Second

BOTH HANDS

Therblig	Mask Numbers 1		2V		2H		3		4V		4H	
	R	L	R	L	R	L	R	L	R	L	R	L
St. +G.	484	589	563	580	536	574	475	554	561	624	574	607
Lead St. +G.		−81		−5		−54		−57	+105			−80
T.L.	265	225	248	233	239	223	274	226	305	248	257	296
Lead T.L.	+92		+76		+22		+35		+61			−127
P. +R.L.	261	205	337	322	456	399	474	428	562	544	572	533
Lead P. + R.L.	+59			−2	+16		+22			−3	+13	
T.E.	183	173	158	179	148	188	195	190	216	240	183	182
Lead T.E.		−15	+45			−59		−30	+23			−32
Total Cycle Time	1192	1192	1287	1313	1381	1383	1418	1398	1644	1656	1586	1618

RIGHT HAND ONLY

St. +G.	287		296		313		299		346		339	
T.L.	213		184		202		208		209		211	
P. +R.L.	242		267		315		343		476		486	
T.E.	128		171		170		158		175		157	
Total Cycle Time	871		917		1000		1008		1206		1193	

Therblig	Mask Numbers 5V R	5V L	5H R	5H L	6V R	6V L	6H R	6H L	7V R	7V L	7H R	7H L
BOTH HANDS												
St. +G.	575	664	559	548	557	714	596	683	622	765	692	628
Lead St. +G.		−28	+193			−10	+124			−104		−64
T.L.	278	267	292	252	320	271	313	235	318	271	270	283
Lead T.L.	+41		+48		+88		+36		+81			−113
P. +R.L.	643	573	605	587	839	769	748	679	845	812	721	737
Lead P. + R.L.	+40		+10			−23	+31		+8			−47
T.E.	290	222	217	191	288	210	189	172	230	176	189	231
Lead T.E.	+34			−44	+199			−13	+11			−18
Total Cycle Time	1786	1727	1673	1578	1983	1946	1847	1770	2015	2024	1873	1879
RIGHT HAND ONLY												
St. +G.	401		330		350		354		379		329	
T.L.	217		231		220		222		217		226	
P. +R.L.	419		515		525		590		536		680	
T.E.	208		178		162		191		190		147	
Total Cycle Time	1245		1254		1257		1358		1323		1382	

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